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# THE OPTICAL IMPRESSION

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*To my wife*

*To my father*
*To my mother*
*To my brother*
*To Jacqueline*

*To my family and in-laws*

*To my friends*

*To our judges*

Doctor Jean PARRET
Associate Director of the U.E.R. of Odontological Sciences
President of thesis

As the soul of the fundamentalist team, his good advices and his experience of life made us discover biology and the philosophy of research.

This work is only the humble reflection of what we all owe him: open our road to the future.

Let him find here the sign of our gratitude.

Mr J. DUMAS

Assistant Lecturer
Professor at the Lyon Sciences University

He taught us and also opened the doors of his laboratory for us to work in complete freedom.

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Lastly his corrections lead us to a more and more precise way.

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Associate Director of the U.E.R. of Odontological Sciences

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The way he united his team with friendship makes us pay tribute to him every day for being part of it.

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Director of the U.E.R. of Odontological Sciences

He was our teacher, he honoured us by his interest in this work and accepted to judge this thesis.

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Assistant Professor at the U.E.R. of Odontological Sciences

He was the first one at the Dental School to encourage us to continue on this road and each month he gave us explanations on the optical impression as it is practiced today.

Let him find here a token of our gratitude.

*and my friends : BERTRAND, FRANCOISE, PAUL, DANIELLE, JACQUES and BERNARD.*

*To Mr Georges LABE*

…

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Assistant Professor at the U.E.R. of Odontological Sciences

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Professor at the INSA

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- Professor SICCARD
(Professors at the INSA)
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- Professor BERTAGNOLIO
- Mr SIRODOT, Mr GALMICHE, Mr CHRETIEN, Mr MARCHAND, Mr MEGE

lastly Mr Bernard DURET and Mr Robert DURET
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- To Mrs M.-T. PAIRON
She probably had the hardest task i.e. typing this text.

- To Mr A. THUSY and Mr C. FOUGEROUSSE
They have tried to give an artistic touch to this austere work.

The very short delay we had did not allow us to control and correct this text.

Please apologize any “mistakes” or “errors” that you may find.

# WARNING

This 2nd cycle thesis has no experimental character, only a bibliographic character. It aims to state the data known to day of a particular type of problem. This way, it seems difficult in a bibliography thesis to refer to only fifty books considering how huge the field is concerning the impression and the making of a prosthesis.

The most important bibliographical part concerns the impression and the laser biological action as numerous studies can be found on this subject. The other parts concern general books which aim to orientate potential researches.

The variety of the study (laser then TV and after that the computer and machine tool) results in the theoretical research idea derived from examining the zonar principle.

We have studied the intervention possibilities and conditions of specialists in each subject, we have looked for links for these various techniques and ensure their coordination to apply them to our activity.

It was relevant before all, to allow the surveillance of making “pieces” requiring “micron” precision by the application of mathematical and physical sciences.

On the other hand, the laser allows to cancel the irrational use of the micro-sensor.

With the risk to derive from the subject, we made a point to deal with the atom and the laser.

In fact, this presentation and the related calculations aim to notice that one spot of the hologram represents, by its intensity, the distance that separates it from the source.

Also, reflection has rules and it is mathematically proved that the energy reflects the distance run by the electromagnetic ray.

Then it is important to consider that the electromagnetic wave carries this energy maker and to look for the reasons why this wave looses energy proportionally to the distance and where the various energies come from.

One should not mix several various energies to exactly translate a distance which explain the remarks about the energy source, what it is (atom) and what it represents in laser.

Lastly, we finally have drawn the possibilities of utilization and limits of laser use, in our study's “concrete” case and the reasons making this utilization possible based on known facts and so allowing the forecasted use achievable practically.

Lyon, France
October 15th, 1973

80 copies of this thesis have been edited.

# - INTRODUCTION -

This work aims to complete a set of tools allowing in a few hours to make an impression, a simple or complex fix prosthesis, any skeletal removable prosthesis and an anatomical related type impression without having to cut the skin.

The impression is made with a laser (He NEON for example) and its recording in nano-second is made on a holographic board.
This hologram is studied directly then on an analyzer tube (TV camera type for example) to produce the intensity function into a distance function.
The successive numbers of the analysis are sent to a computer which allows a numerical command machine to sculpt an impression in the mass by various processes (Araldite, steel…), then to sculpt a crown or any other metallic part (gold, steel).

The working time would be a few hours even for a complete bridge, cutting would be a few microns precise and the production in “n” copies would be possible without any modification in time.

The first chapter is a critique of the traditional techniques. Chapter two concerns the study of what the laser is to allow us to choose, chapter three deals with the effect of the ray on the organism. Chapter four explains the hologram, in the fifth chapter the analysis by camera is explained, in chapter sixth, what the computer allows us to do is described by reminding what it is. Chapter seventh deals with the numerical command and chapter eighth about the various machining available to us. Finally chapter ninth explains what this idea can enable us within general practice and most of all in our field.

Chapter tenth is a bibliography classified by chapters and later by authors names classified alphabetically.

# - SUMMARY -

# THE TRADITIONAL IMPRESSION

## A critique

**- HISTORY**
**- DIMENSIONAL VARIATION**
**- PRECISION TENDENCIES**
**- OUR METHOD**
**- THEORETHICAL RESEARCH AND OUR PROFESSION**

# CHAPTER – I

## I – 1 – HISTORY

[1-2-3-4]

Our study extends from the impression to the inlay and includes the electric lancet. But our investigation centers on precision which leads us to the problem of the impression and its quality. A little history seems relevant.

The first impression was done in wax by PURMAN in 1711 [1]. In 1728, FAUCHARD laid the basis for our profession and for impressions [2].

"Before inserting the pivot, the dental cavity must be filled with powdered mastic" p. 227 .
"Two ounces of flat gum lacquer
One ounce of therabentine of Venice
Two ounces of white coral powder"
(Dental Surgery of the Treatment of Teeth, Volume II, Servières, Paris, 1786).

A doctor in BRESLAN (1648-1721) speaks of an impression in virgin wax with a casting in ivory from a horse, a hippopotamus or from the bleached hoof of an ox. [2].

Wax was improved by PFAFF in 1756 but it was not until 1845 that plaster appeared with WESCOTT and DIWINELLE. In 1848, gutta-percha's made its appearance (de la BARRE 1852 at Masson's) and in 1856 STENS created the first thermoplastic composition.

This was improved by GREEN in 1907. Hydrocolloids were used beginning in 1925. We have come a long way from our ancestors'use of beeswax [3] and the work of Nicolas DUBOIS de CLEMENT in 1791 [4].

In 1928, the ADA became the basis for all current products. In 1939, amalgams appeared and from 1945 on, synthetic elastomers, zinc oxide pastes and Eugenol dominated the market…

Today we can say that there are as many products as methods. We are going to succinctly recall them and especially define their precision.

## I – 2 – DIMENSIONAL VARIATION

### I – 2 – 1 – See drawing n°1

This is a general diagram of the procedures used for any kind of filling (total, partial).

We note the following concerning these operations:
- For an indirect imprint, we reach about eight impressions which means more exactly that out of eight times the precision is only function of the materials and sometimes of the used techniques.
- For a direct impression the problem occurs four times.
- For a direct filling, it occurs once.

Amongst the functions inherent to precision assuming the techniques used are perfect, dimensional stability remains an obstacle for us.

In fact, if we use the materials under strict conditions ($t^0$, pH) their variations remain a constant problem and only "some kind of home made protection", by using a few tricks of the trade we can mitigate the difficulty.

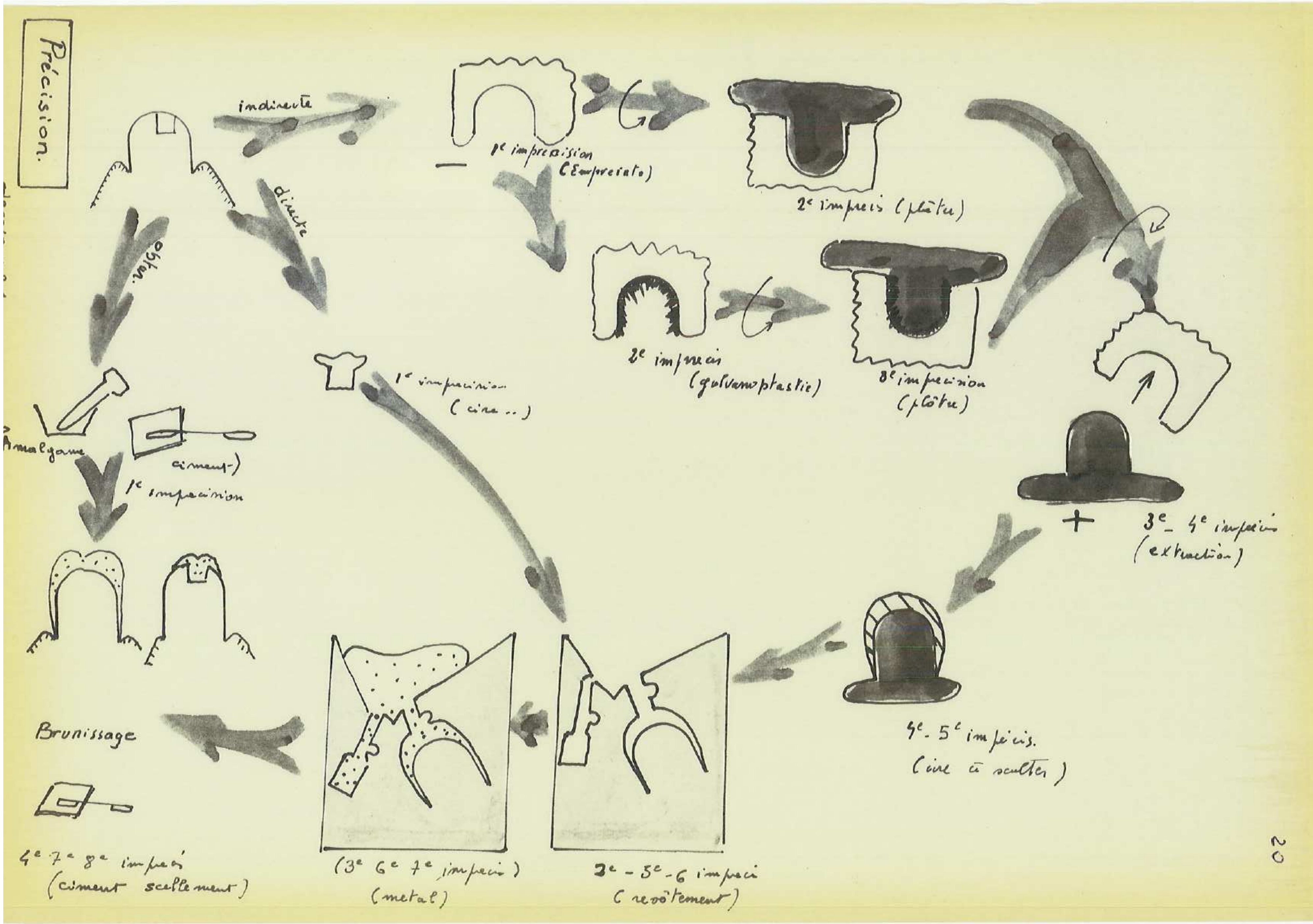
First, we will review all the dimensional variations then all the independent factors (influenced by us or by our techniques) of the product itself. Thus we will arrive at our own notion of precision compared to that which is currently accepted.

<u>I – 2 – 2 – Products for making hard impressions</u> [1–3–5–9–10–12–
<u>Linear dimensional variation</u> 16–31–35–41-42]

<u>I – 2 – 2 – 1 – Plaster</u> : [17–18–19–20–21–22–23–24–26-27]

It is a calcium semi-hydrate, formula $SO_4\,Ca\,\frac{1}{2}\,H_20$

Two points will be covered:
- expansion of the impression
- granulometry


Précision.
indirecte
directe
obten.
1e impression (Empreinte)
2e impress (plâtre)
2e impress (galvanoplastie)
3e impression (plâtre)
1e impression (cire ..)
3e _ 4e impression (extraction)
4e - 5e impress. (cire à sculter)
Amalgame
ciment-)
1e impression
Brunissage
4e 7e 8e impress (ciment scellement)
(3e 6e 7e impress) (metal)
2e - 5e - 6 impress (revêtement)
20

a) Granulometry

Plaster possesses various crystallizations (larger or smaller according to how they are obtained) which in dentistry are:

- Hemihydrate α (obtained at 110° under steam pressure)
- Hemihydrate β (obtained from 150° to 170° under atmospheric pressure) (drawings 2a and 2c) [16-19-20-23-24]

b) The faster the impression, the greater the stability and accuracy.
(drawing 26)

c) Expansion of the impression : [24-31-1-5-18-26-27]

◦ SKINNER notes that, depending on the product, there is an expansion [31] during the transformation of the hemi-hydrate into a bi-hydrate comprised between 0.06% and 0.5% with a volume inferior to 7.1% of the two used volumes $\frac{water}{powder}$ ($\frac{E}{P}$)
This contradiction is due to the phenomenum linked to crystallization (drawings 3a-b).

◦ For [1] we have two phenomena : - Dehydration – change in the crystalline network in addition to the reaction (drawing 2d). There is an expansion of 0.1%.

◦ The expression [5] for WALLES is an expansion of 0.4% to 0.5% increased by immersion (applied to the hydroscopic coating) reduced to 0.06% ($K_2 SO_4$) or even 0.04 % (DUROC 7 days, drawing 3).

◦ For DURVILLE [18] variations are integral parts of the plaster. They can be divided in two:
- chemical origin: increase of 43% concealed by 7.3% (hydration) and according to the $\frac{E}{P}$ relation (fixes the porosity).
- physical origin: the dehydrated crystals (drawing 3a) push each other provoking a true dilation which is increased by any manoeuvres that shorten the induction time (drawing 2d). The contraction shrinkage is only 1/10°.

◦ For [26] opinions are mixed. The accelerators (p.8) do not affect the expansion of the impression, but it does later…

◦ For PEYTON, it is 0.05% to 0.09% which results in an expansion of 4 to 5 μ for 1 cm or 30 to 40 μ for each small impression.
"Everyone says plaster expands, but no-one says when and by how much" (COCAGNE 1946)
"Even so, many people using it in the building industry says it contracts". (PIERCE 1965)
So despite SCHILLER's equation, which seems to me quite complex to describe a crystallographic phenomenum [18] we can say considering drawing 3b :
-there is a completely unverifiable variation in space;
-there is undeniably a variation in time.
We count on a precision of approximately 0.4% or 60 μ [27-16]. This is a wild variation.

<u>I – 2 – 2 – 2 – Thermoplastic pastes</u> (KERR) [25-28].
See A.D.A.

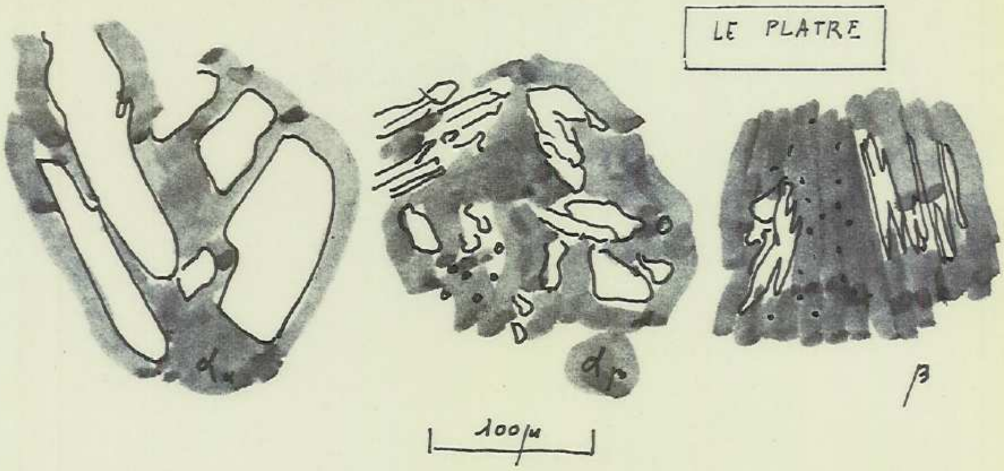
a) 37% resin
18% stearic acid
45% $M_g$ $SO_4$
Plasticity between 50 and 57°
One problem: the impression expands

b) ◦ [16] uses a high precision method and allows relief impressions.
Considering the galvanoplasty, the precision equals 40 μ. There is no time factor.

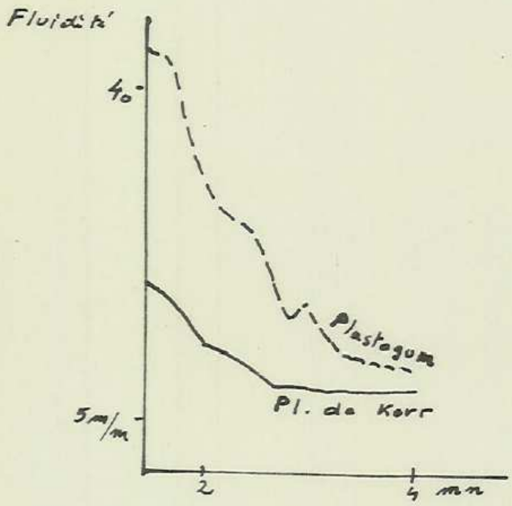
◦ For [1] there are imprecision factors in crystallization at 44° of certain crystals (drawing 4a).

◦ With NALLY, one can speak of a linear retraction [5] of approximately 0.3% to 0.4% (between 37° to 25°). Therefore, the impression is cast immediately. There is no storage.
In addition, for a single impression, KERR's paste can undergo a residual formation of 0.04 [28]. It can become deformed if the shrinkage is not in the axis.
There is a certain instability of around –0.4% and an evident risk of deformation (drawing 5a).

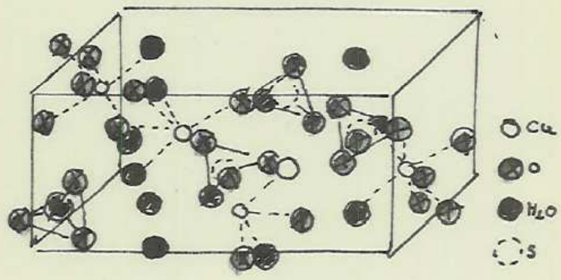
LE PLATRE



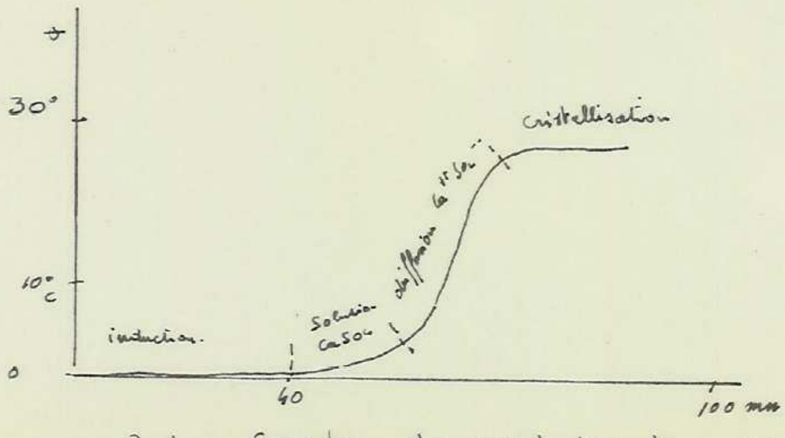

2 a cristaux du plâtre (granulométrie) [15 19 20]




2 b temp de prise [19]

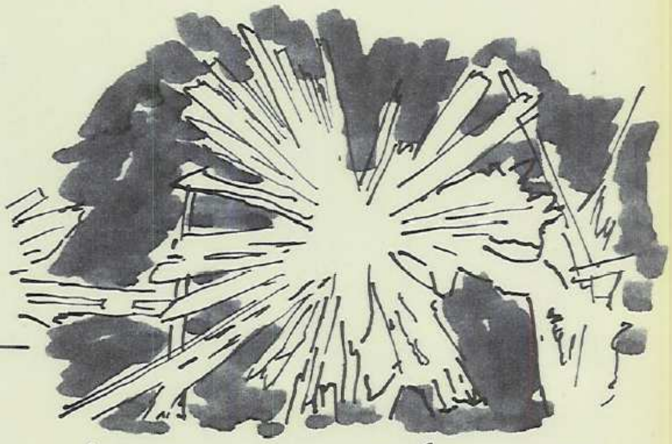



2 c Structure cristalline Gypse [23]



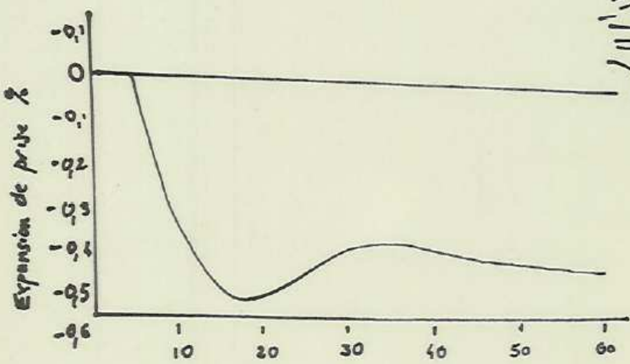

2 d Courbe de cristallisation (24)

# Le Plâtre (Suite)

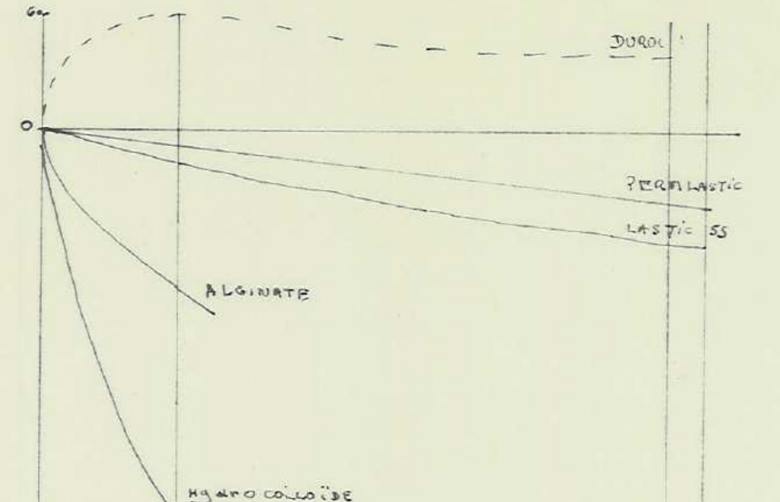


Agglomérat typique de cristaux après formes (Smith) [31]

dessin 3a.




Variations dimensionnelles pendant la prise d'un dérivé du gypse
(Docking) [31]
dessin n° 3b




Courbes comparatives des 4 groupes de matériaux à empreinte et du plâtre Extra dur

dessin 3c

### I – 2 – 2 – 3 – Zinc oxide pastes [29-30]

Composition base: a) zinc oxide [5]
b) "liquid" essence of cloves 56% and oil 28%

◦ For NALLY [5] the contraction of 0.1% is negligible. It can be cast slowly but it is too sticky.

◦ ROUCOULE [16] speaks of a modification which attains the form of 40 to 160 μ (drawing 5b).

◦ For LEJOYEUX [1] the dimensional stability is more than sufficient in a complete prosthesis (with a contraction of less than 0.1%).
The thinner the material, the more the stability (good already) is important in time [1].

◦ SKINNER [31] remains in the same values of 0.1% inferior if the impression holder has a total dimensional stability.

### I – 2 – 2 – 4 – Conclusion

-A dilation of plaster of (0.5 to 0.05)
-Two contractions: thermoplastics (0.3 to 0.4)
zinc oxide (0.1)

## I – 2 – 3 – Elastic impression pastes

[same as I-2-2]

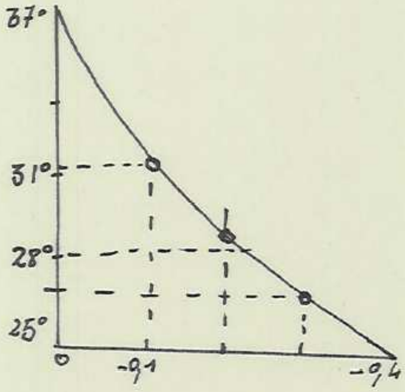
### I – 2 – 3 – 1 – Hydrocolloids [28-32]

Composition : soil $\rightleftharpoons$ gel : reversible

soil $\longrightarrow$ gel : irreversible

a) Reversible hydrocolloids

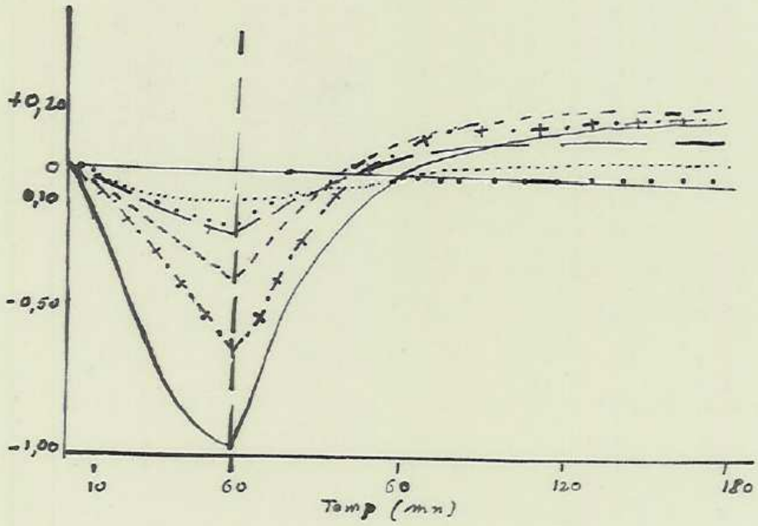
◦ For ROUCOULE [16] there is contraction then dilation (see drawing 5c) or a variation of ± 10 μ.




Instabilité dimensionelle
(thermoplastique)
(dessin 5a.) [16]

| | |
|---|---|
| Luralite de Kerr | − 0,000 |
| Ash | − 0,004 |
| SS. White (hard) | − 0,004 |
| SS White (soft) | + 0,008 |
| Alston | − 0,012 |
| cero-plus | − 0,012 |
| Nelly | − 0,016 |
| Momax | − 0,016 |

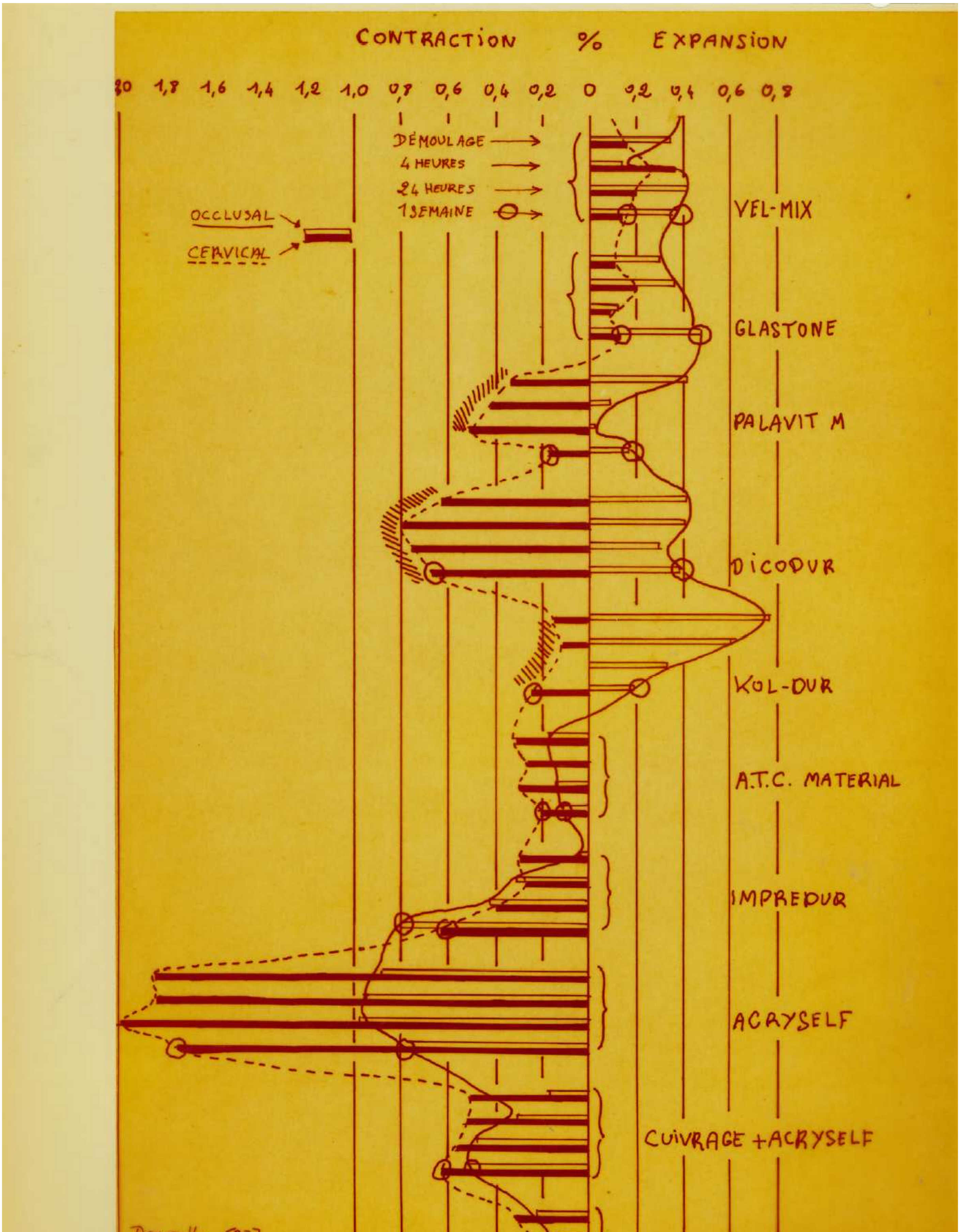
Instabilité dimensionnelle
(ox de Zn + Eug.)
(dessin 5b) [16]




contraction linéaire (hydrocolloïde réversible) [31]
(6 hydro différent) degré hydroscopique const.

(dessin 5c)

thermoplastic
oxyde de Zn
hydrocolloïde



CONTRACTION % EXPANSION
2,0 1,8 1,6 1,4 1,2 1,0 0,8 0,6 0,4 0,2 0 0,2 0,4 0,6 0,8
DÉMOULAGE
4 HEURES
24 HEURES
1 SEMAINE
OCCLUSAL
CERVICAL
VEL-MIX
GLASTONE
PALAVIT M
DICODUR
KOL-DUR
A.T.C. MATERIAL
IMPREDUR
ACRYSELF
CUIVRAGE + ACRYSELF
CUIVRAGE + VEL-MIX
Deyrolle [27]
dessin n° 4

◦ NALLY [5] believes this elastic material is very precise and it allows fine details to be recorded without compression. It also lets you take the overhangs. But [5] it is not an impression that can be done in a hurry. It cannot be metallized and it must be cast immediately.

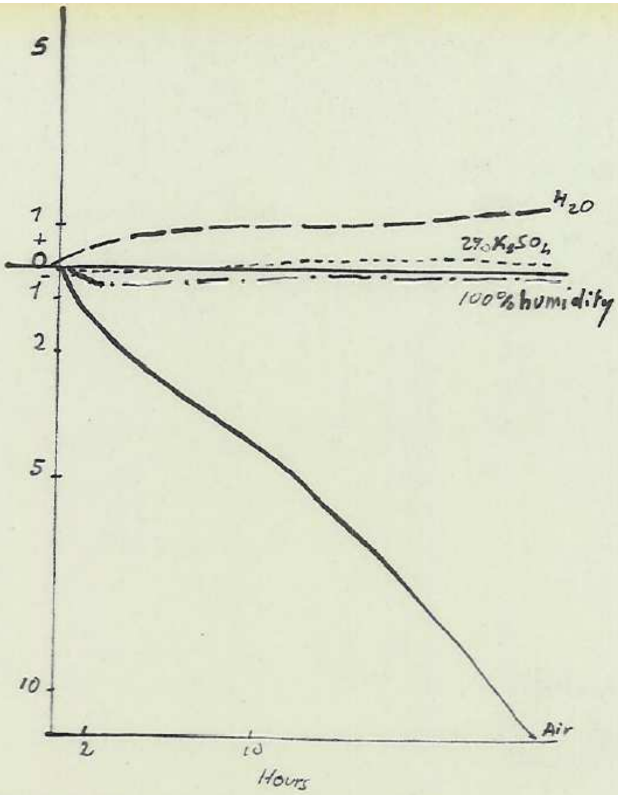
◦ According to PHILLIPS and SKINNER [9] and [31], the storage factors are very precise. Six other factors affect the imprecision [9 p. 116] but we will not spend time on them. The reasons for the variations in dimension are the syneresis and absorption. The syneresis is produced as soon as retraction from the mouth occurs. Even an immersion does not restore its proper dimensions. We get a general over-expansion of 0.1% perhaps even more. There are also constraint zones [32] (drawing 3c).
◦ [31] Whatever the storage conditions (potassium sulfate), it is impossible to mitigate this failure except in a manner even more inexact (a variation in the compression mass is therefore irreversible [31] (drawing 6a).

b) Irreversible hydrocolloids (alginate) [33]

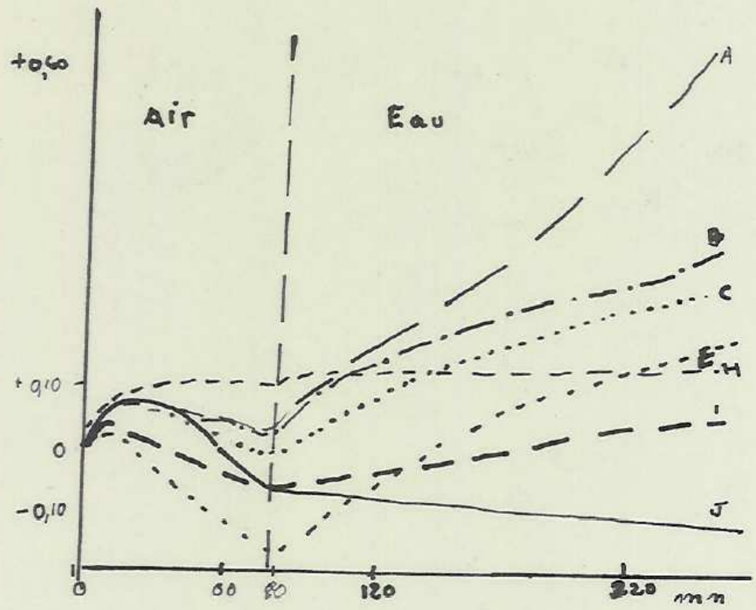
The basic element usually consists of a sodium alkaline alginate or a water-soluble potassium [1]. Any alginate presents a larger or smaller contraction or dilation in time (drawing 7c), according to BACHMANN [63].
The waiting time in the open air or in a basin of water always provokes deformations in the materials, especially in the maximal thickness zones (it is better to have a humid atmosphere than water).

◦ For ROUCOULE [16] the degree of precision is the least good of all the materials. The dimensional stability is weak, the degree of precision mediocre: (625 to1750 μ) as opposed to 10 μ for the reversibles, and 35 μ for the silicons (see [293 p.40]). One can speak of a precision [6] according to the alginate of 0.1 to 0.3. Meyer reaches 0.7% [33].

◦ PHILLIPS and SKINNER speak in the good case of a stability of 0.1% (drawing 6b) according to the conditions.




Stokage (dessin n° 6 a) [3]




alginate stokage (dessin n° C b) [3']

Hydrocolloïde
Stokage

◦ NALLY uses as a base the results of BACHMANN.
Variations other than linear ones will have to be considered.

### I – 2 – 3 – 2 – Elastomers (elastic polymers) [31]

Synthetic rubber considered as colloidal hydrophobic gels [28]. The polycondensation of the base rubber is made by a chemical reaction with a liquid (it is not a catalyst).

a) Thicol or polysulfuric rubber (Permlastic [34])

The dimensional stability can be linked to several factors. We note primarily [28] :
- Time : the longer the impression remains in the mouth, the more precise it is.
- Stability of the mouth
- Temperature
- The imprint accompanied by a mild stability (15 minutes) then retractibility.
- Conservation : cast immediately, there can be a continuation of the polymerization (within one hour). The impression holder can be water-sensitive and the air bubbles can produce bumps in the die.

◦ For ROUCOULE [16] we have an initial contraction of 0.03 to 0.05% or 3 to 5 μ for 1 minute. In three days it surpasses 0.11 to 0.13% which represents only 11 to 13 μ.
Recommendation [29] for the juxtra and supra gingival impressions.
The wash technique (double impression) is interesting.
An average of 4% for a 24-hour time lengthening
An average of 19% for a 10 hour-time [34]
The results have been well demonstrated (pages 33 to 36 of [4]).
Increasing the catalyst only makes the impression sticky [1] and therefore imprecise. The impression is due to a secondary polymerization (0.05% in 36 hours and 0.13% in 3 days) (drawing 8a).
The wash technique (lightest coating) decreases the distortion (drawing 8b).

◦ SKINNER and PHILLIPPS speak of 0.03 to 0.05% at 30 minutes and 0.11 to 0.13% at 3 days [32].
As with Bachmann, there are decreases in the length of the specimen (linear function of time) [6].
It has a weaker value than the silicon and conservation in open air is possible. It is cast immediately.

b) Silicons

Silicons offer less precision at the beginning and over time than the polysulfurs (drawing 8c).

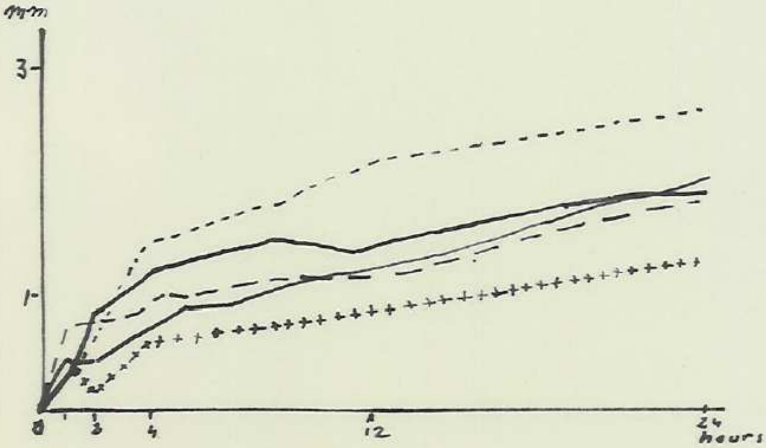
◦ ROUCOULE [16] places the values of the contractions at 0.05% and 0.08% in 30 minutes, or 5 to 8 at the beginning and 0.37 to 30 in 3 days, or 37 to 30 afterwards.

◦ BACHMANN [6] records slight variations (0.086 after 170 hours).

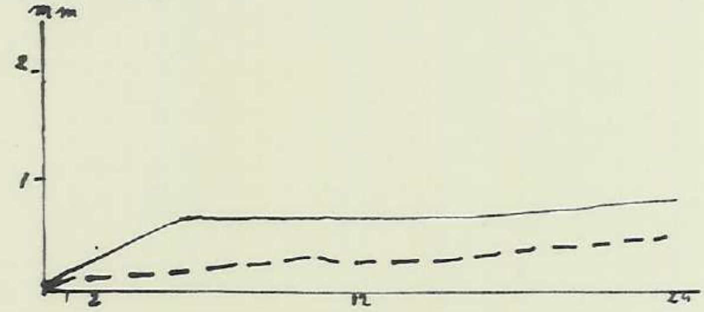
◦ SKINNER and PHILLIPPS arrive at 0.03 at 30 minutes and 0.3 to 0.8 in 3 days [9, 31].
The distension values are very well translated in [1] by A $^{10}$ 14 (drawing 9a).
The drawing shows that the dimensional stability is a function of:
- the thickness
- the polymerization time
- the casting time
- the number of models taken from the impression (drawing 9 a-b-c and d).

We note that, like silicons [16], the polysulfurs have significant variations between the time needed to prepare the models and the length of the pause after the impression.

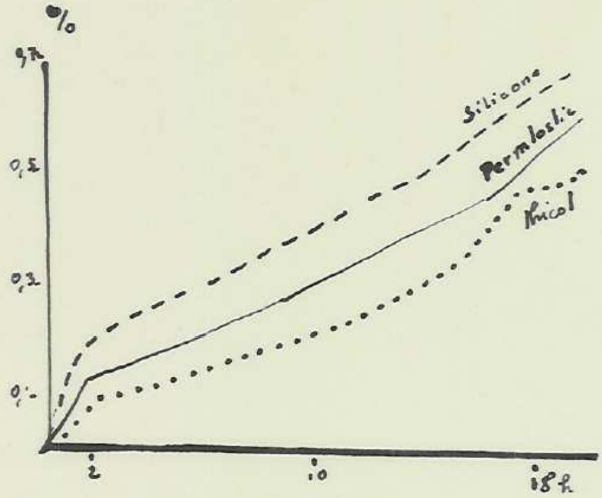
c) Mixed elastomers [1-16]
Commercial protection ineligible for medical products.
Modified Lastic of 0 to 2.6%.
Xantopren 7.5% to 19%.
Optosil however from 7.5% to 6%.
There are marked differences in the behavior (drawing 10a) of synthetic elastomers between the [14] and the left and right.




Thiocol (stabilité temporelle) [1]
dessin 8a

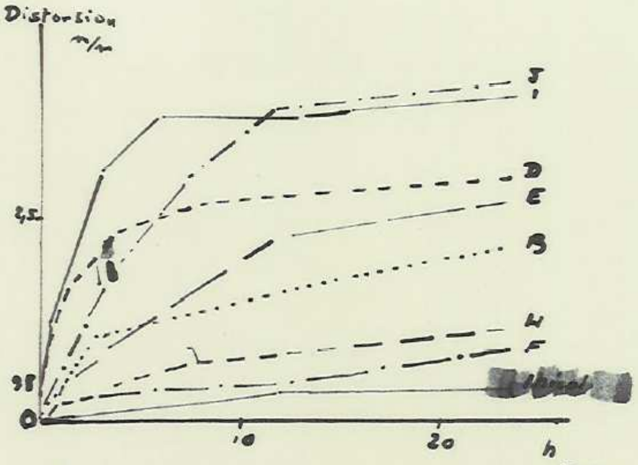



Thiocol (Wesh. techique) [1]
dessin 8b

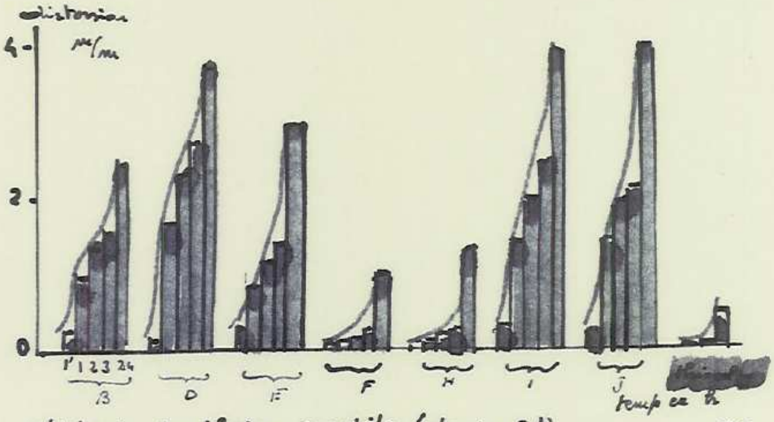



Comparaison Thiocol Silicone.
dessin 8c [1]

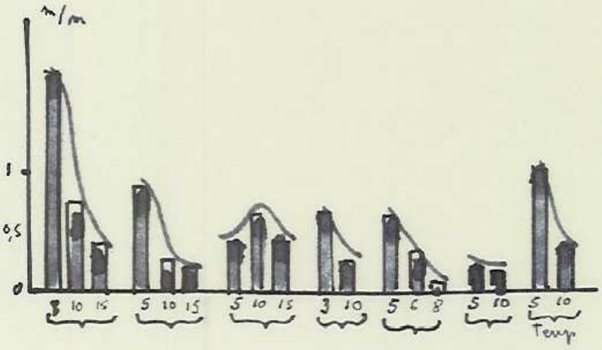
Thiocol
Silicone
mixte



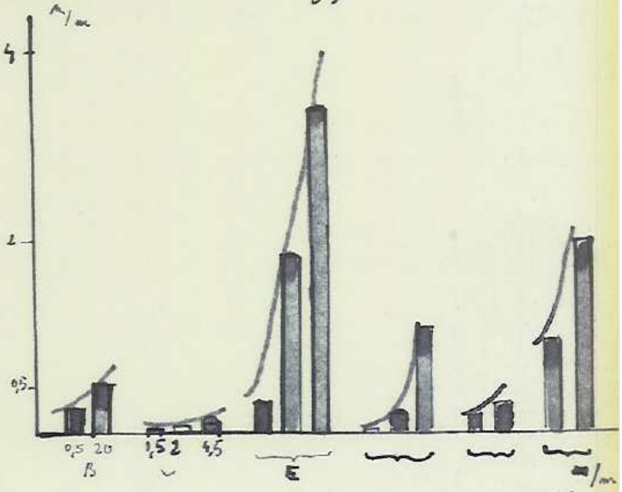

distorsion avec le stokage à l'air [1]




distorsion sur plâtre modèle (dessin 3b) [1]




distorsion de polymérisation (dessin 3c) [1]




distorsion et épaisseur (dessin 3d) [1]

Thiocol
Silicone
(distorsion)

I – 2 – 4 – Gelatin

Gelatin allows the casting of several impressions. Its precision is from 20 to 60 μ approximately [16], according to the brand.

-Example [16]

C and J - error goes from 0.2 to 0.5% for the 3rd model
Virilium error goes from 0.4 to 0.6% for the 3rd model
Multigel error goes from 0.3 to 0.4% for the 3rd model
Vidur error goes from 0.2 to 0.4% for the 3rd model
Croform error goes from 0.3 to 0.4% for the 3rd model

I – 2 – 5 – Direct impression paste

I – 2 – 5 – 1

Direct impressions pastes were the only materials used after the 18th and 19th centuries.
They had a resurgence in popularity since 1956 [1].
The basic composition consists of parafin, beeswax, ceresin and spermaceti.
These compounds have negligible volume modification during thermal variations [1]. They also have great dimensional stability.

- Inlay wax can be mineral, vegetable, synthetic or natural [28]. A thermal expansion curve was established by PEYTON [35] (drawing 11d).

◦ ROUCOULE found that [16] these pastes lose from 1 to 6% during the cooling period, or a difference of 30 to 40 μ.

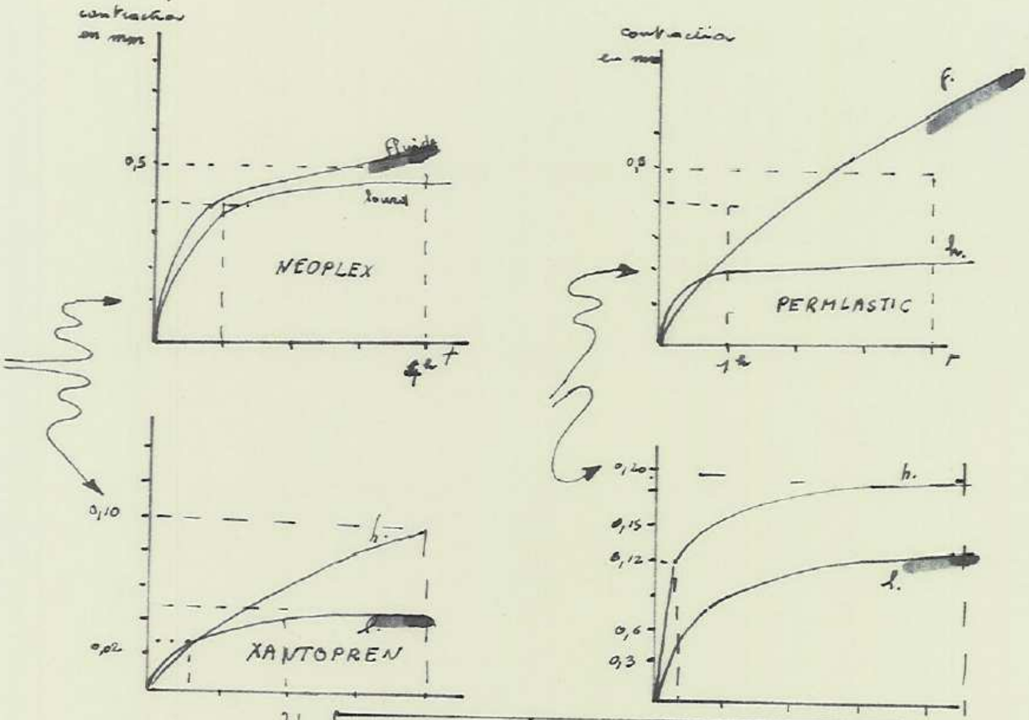
◦ According to PHILLIPPS and SKINNER [31], the linear dilation is very marked : 0,7% for 20°C or a contraction of 0.35% passing from 37 to 25° (see KERR's paste) (see drawing 11 c-d).

◦ NALLY admits, with reservations, a conservation of 4° [5].

◦ According to DEMELON [28] wax has a contraction of 0.45% between 37 and 20°. This expansion depends on the consistency of the wax.

| | | |
|---|---|---|
| 50°C | Soft | 1% |
| 50°C | Medium | 1% |
| 50°C | Hard | 1.2% |

Wax is highly subject to deformations.



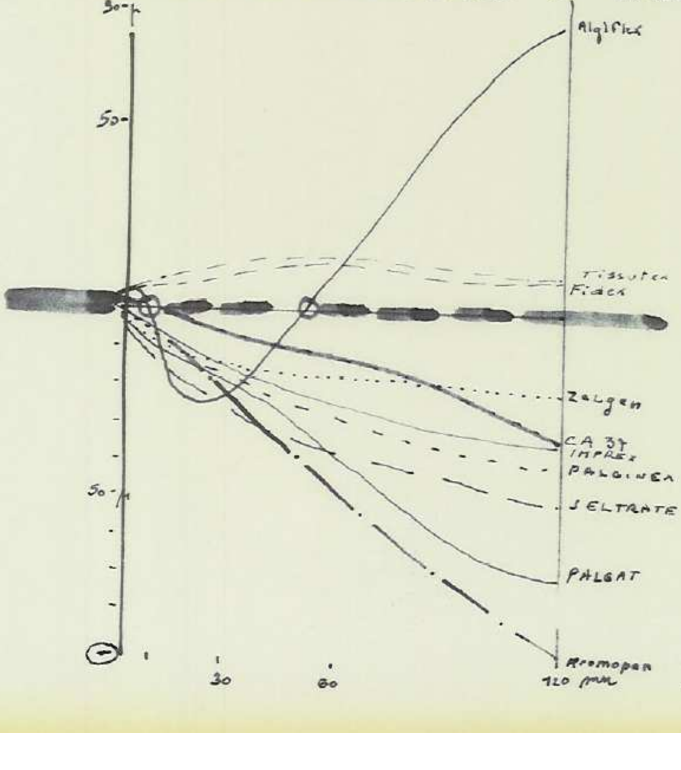

ELASTOMERES DE SYNTHESE

Echantillon 10 mm de ø et de hauteur

37°C 1 atm. capteur sensible ±4μ

(dessin 10 a)

(+) (travaux de MM Caitucoli et Lussac)

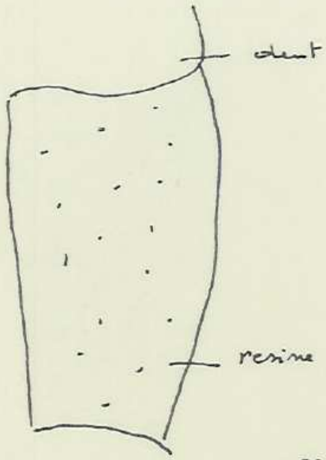



ALGINATE

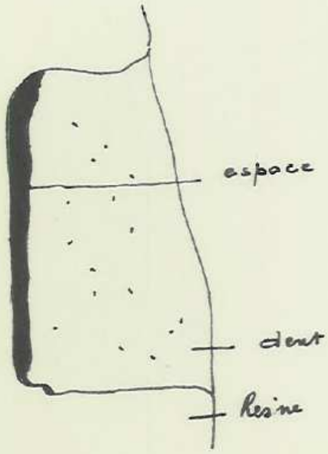
Echantillon 10 mm ø et h.

(travaux de BACHMANN)

(dessin 10 b)

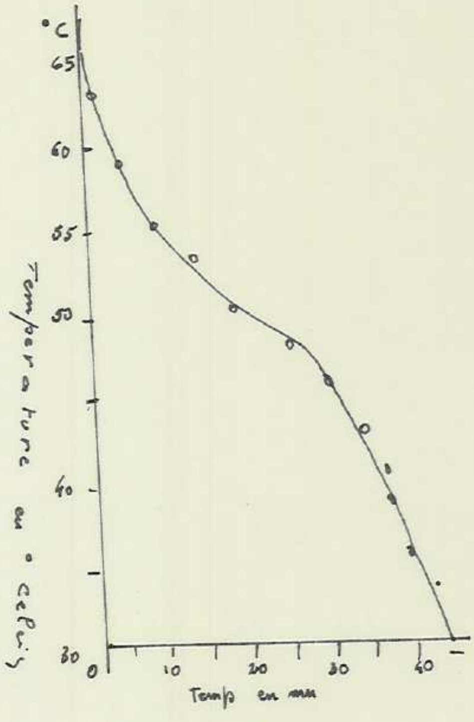



Resine autopolymérisable
technique du pinceau.
(dessin II a) [28]

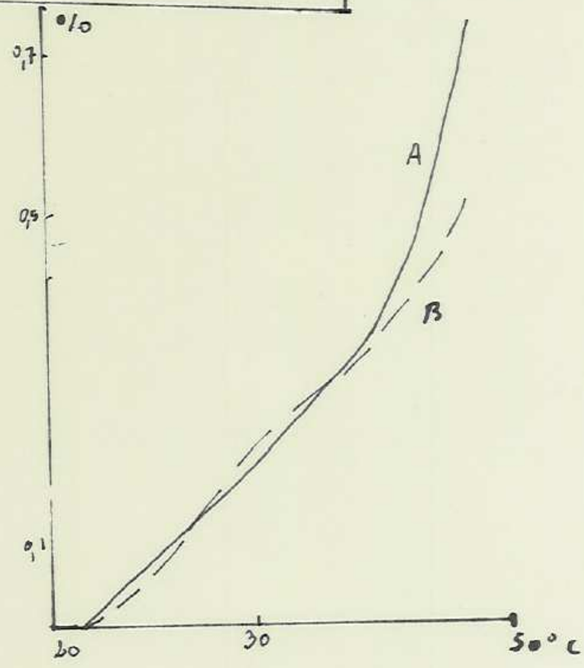



Résine autopolymérisable
technique compressive.
(dessin II b) [28]

Resines . Empreinte
directe




Fluage de cire
(dessin II c) [28]




dilatation d'une cire à
Inlay (A sous pression constante
et B sans pression)
(dessin II d) [28]

Cires à Inlay

### I – 2 – 5 – 2 – Resins for impressions

Resins are part of plastic matter, composed of a polymer and a monomer, which results in polymerization.
To make an impression, it is not necessarily the thermoplastic resin that interests us but the autopolymerizing resin. The principle remains the same but there is no need for endothermic heat.

a) Autocatalytic resin with a slower grip time

These come in powder and liquid forms (capolymer of methyl metacrylate and ethyl acylate, alcoholic solution synthetic plasticizer for removable prosthesis).
The placement is done with a brush (drawings 11 a-b and 12c) [38].

◦ ROUCOULE [16] arrives at a contraction of 5 to 22 μ.
SWECNEY comes up with 53.

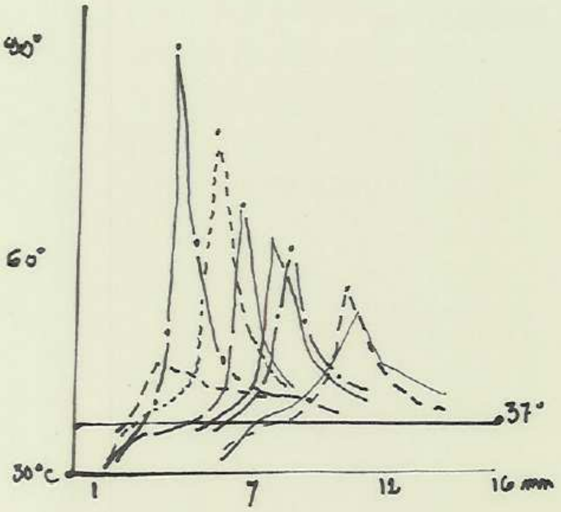
◦ According to SKINNER and PHILLIPPS there is the double problem of dimensional stability and temperature [31] (drawing 12a and b).

◦ As for Nally [5], he brings up 3 problems of dimensional variability :
-The thermal expansion coefficient: serious problem of precision ($81\ 10^{-6}$)
-Change in the volume due to the polymerization (5 to 6%, linear contraction 0.5%)
-Dilation during immersion (1% after 30 days).

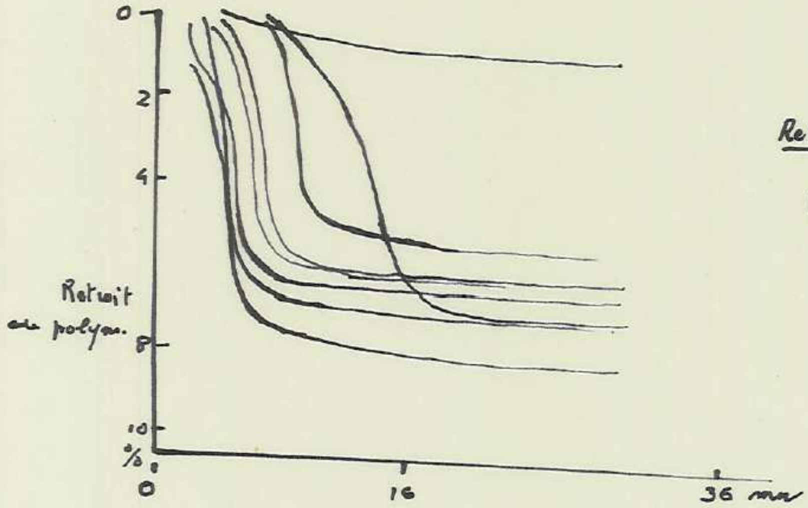
### I – 2 – 6 – Products for the positive

When the impression is taken, two routes are possible.
1 – cast it directly
2 – consolidate it with a galvanoplasty or a resin

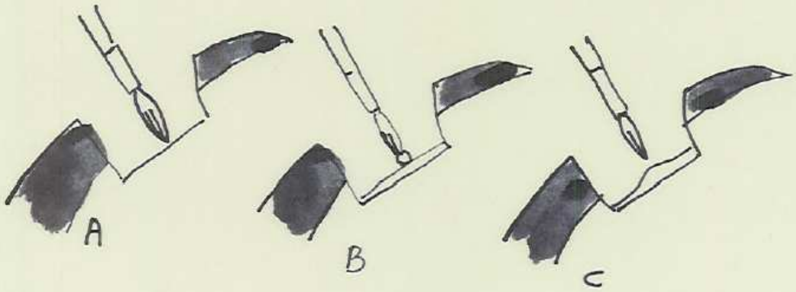
The choice of either possibility depends on the products used and the precision desired.




**Augmentation de température.**
Résine autop. d'obturation.
[31]
(dessin 12 a.)




**Retrait de Volume**
[31]
(dessin 12 b)




**Application au pinceau** [31] (dessin 12c)

Resine

## I – 2 – 6 – 1 – Plaster

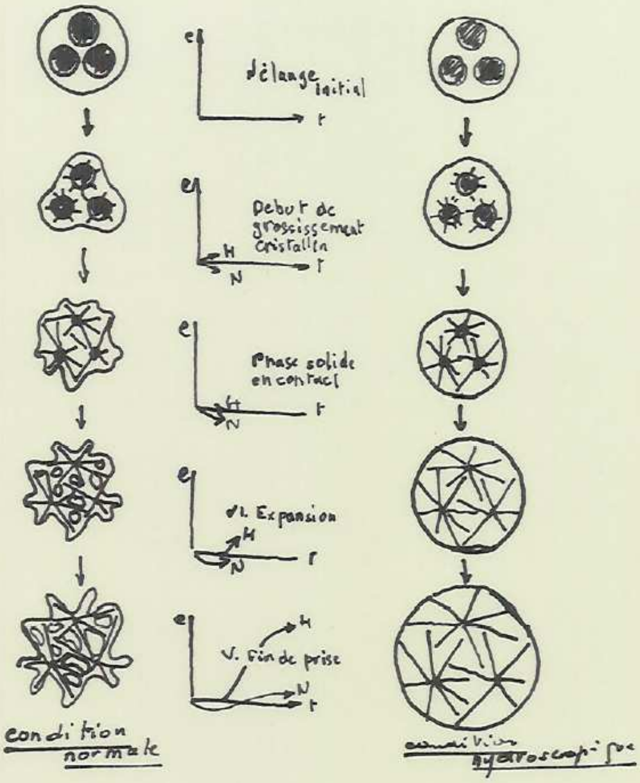
The technical and crystallographic characteristics of plaster are discussed in section [I-2-2-1].
Crystallography shows us that the precision of the grain is tied to a great deal of many factors (water, addition of a catalyst, mixing, temperature, etc..) [5].

a) Plaster undergoes an expansion

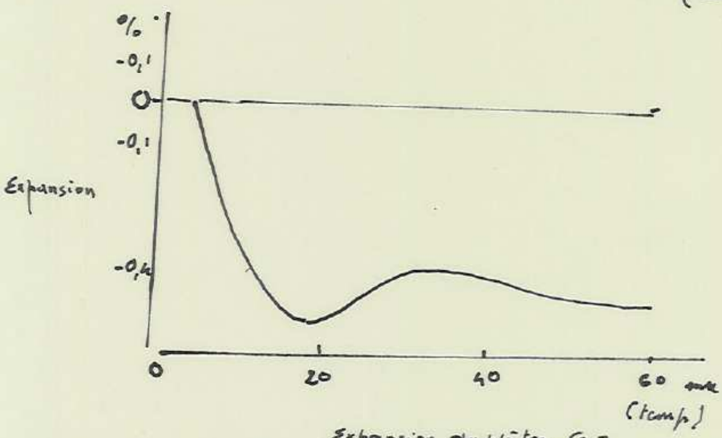
(Velmix Gestone) sometimes, undergoes expansions and retractions (PALVIT).
The time needed to take the impression [26] is usually from 6 to 8 minutes.
(acording to DEYROLLE, the accelerators influence the expansion).
The expansion of the impression (POGGIOLI and NALLY) [5 and 34] is 0.04 for the duroc and the same for the velmise (see below).
PEYRON [35] finds an expansion of from 0.05 to 0.07% resulting in an expansion of 4 to 5 $\mu$ for 1 cm.
The more water there is, the fewer crystallization nuclei for each unit of volume and less growth interference in the crystals [31] (see drawing 13a).
The high dimension space [26] is used for the passage of the sealing cement (0.04%).

b) The impression plasters [5] are usually hemihydrates (harder, less expansion).
The $K_2 SO_4$ diminishes the expansion and the Na Cl increases it.

◦ According to ROUCOULE [16] the plaster stones have a slight expansion
- 0.15 in open air, 0.30% in a hygroscopic milieu (thin) and 0.8 to 1% (large grains)
- the amount of water makes the expansion change in the opposite direction
0.45 → 0.41% exp.
0.80 → 0.24% exp.
- Mixing : 1 minute 0.24%
2 minutes 0.40%
8 minutes 3.4%
(drawing 13b)
◦ SKINNER sets it at 0.06 to 0.05
They note the essential role of the age of the specimen (drawing 13c).

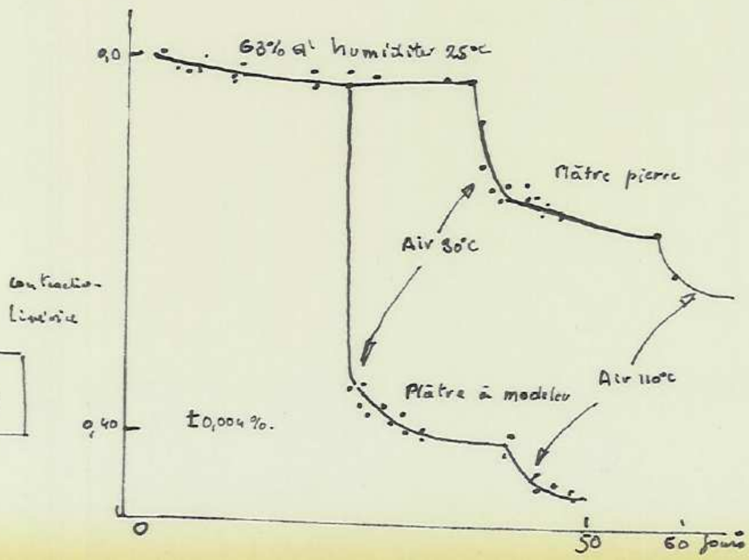



(dessin 13a) [31]




Expansion du plâtre [31] (dessin 13b)

Plâtre




contraction avec l'âge [31]

(dessin 13c)

effet de la température

c) Impression plasters offer little resistance to fracture [26].

d) They result in a hardness of 35 (Knoop) after 24 hours and a resistance to abrasion of approximately 0.248 (Velmix)

e) To the eye, crystallography gives good results [18 and 26] in the form of the details.

f) The model reaction with the impression is null for the plaster.

### I – 2 – 6 – 2 – Copper amalgam

Used on the copper impression, this material [16] is less precise than stone plaster. Its use has been virtually abandoned (see below).

### I – 2 – 6 – 3 – Galvanoplasty [36]

Silver or copper plating.
Silver galvanoplasty on thioplast is well known.
The galvanized impression is filled with plaster. Galvanoplasty on metal is also possible [37].
Nickel galvanization is also possible. The big problem is the internal tension that it provokes.
After a deposit of powdered silver (for example), the interior galvanic coating is obtained.
We note a dimensional variation in the acid and alkaline baths (not forgetting the variations in weight) (drawing 14a).
What can we say ?
Galvanoplasty offers a MPO less over-dimensional than plaster [26] but produces internal tensions. It lacks adherence and provokes the contraction of the deposited resins.
- resistance is superior
- hardness 102 with copper (Knoop)
- resistance to abrasion 0.025 (10 times that of plaster)
- very elaborate details
- needs constant surveillance

### I – 2 – 6 – 4 – Self-polymerizable resins

They are more stable than those polymerized by heat (3 to 4 of imprecision) [16] (see drawing).
The self-polymerizable resins usually have a polymerization contraction limited to their physical compressibility. In direct methods [36] the contraction is limited through immersion (absorption of water).
If we return to drawing 4 [27] we clearly see a dispersion of the dilation and contraction values.

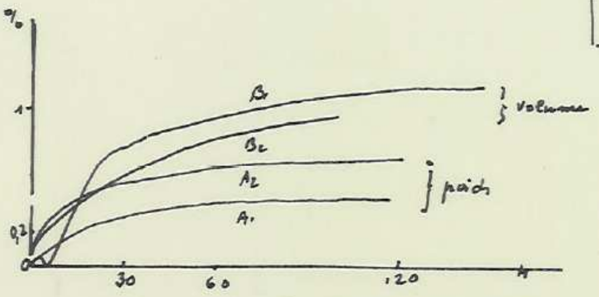
### I – 2 – 6 – 5 – Note

- For certain materials (PALVIT, DICODUR and KOLDUR) we have a dilation per impression followed by an unequal contraction (values of 0.3 to 0.4%).
- The EPOXY resins (ATC ETIMPRIDUR) are contractible from 0.2 to 0.4% (and even 0.6 to 0.8 in 7 days).
- ACRYSELF has a retraction function of 2% thickness !

## I – 2 – 7 – The coating

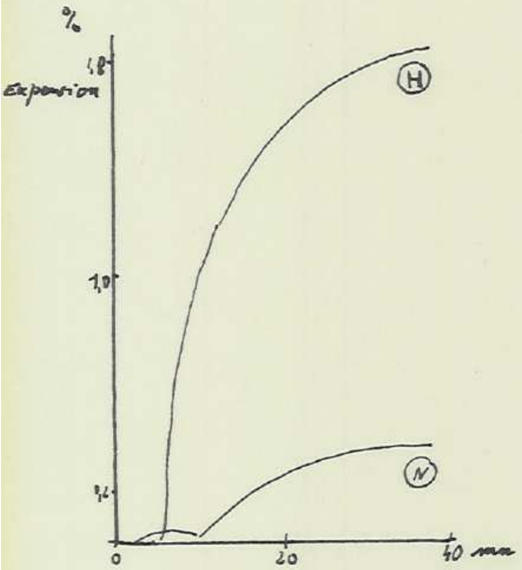
The expansion of the coating usually varies [16] according to the heating and casting methods (thermic or hygroscopic), the percentage increasing from 0.4% to 1.8% or 40 to 180 μ (drawing 14b).
The problem is to compensate for the expansion of the metal [5].
We expect an average linear expansion of 1.65% corresponding to a 0.4% contraction of the wax and of the gold alloy, for example (1.25%). This expansion occurs in three parts (the thermal impression, the hygroscopic impression if desired which gives 4% to 5% without restraints while there is 2% with the asbestos-lined cylinder).
Our drawing shows only the normal and hygroscopic impression [31 to 40].
All coating must be compatible with metal.
- normal precision curve less than 800°C
- high precision curve (for porcelain) higher than 960°C

## Galvanoplastic revêtement



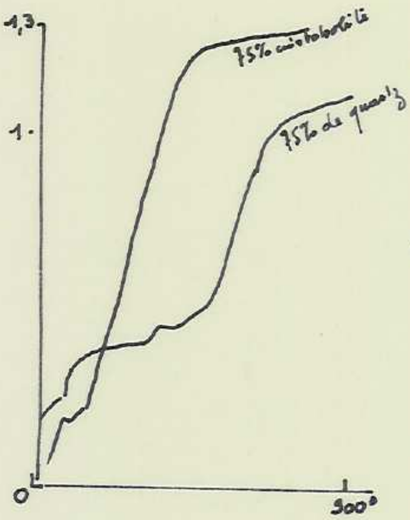

changement de poids et de Volume d'un silicone dans un bain galvanique. De $NiSO_4$ et $AgCN_2$

(dessin n° 14 a) [37] [36]



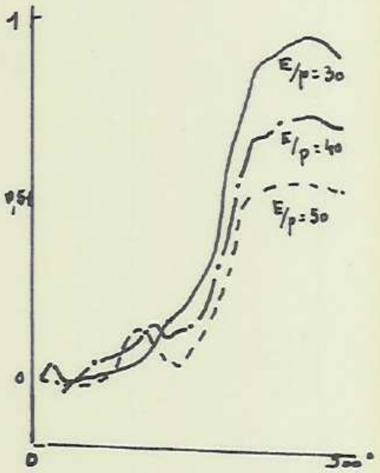

Expansion H et Normale. [43]

(dessin n° 14 b)



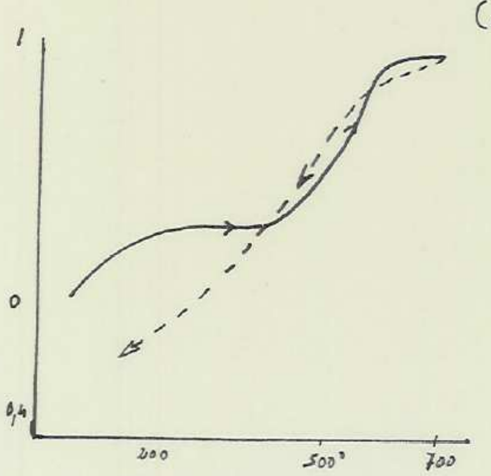

Influence des pourcentage des hemihydrate β et cristobalite [43]

(dessin 14 c)



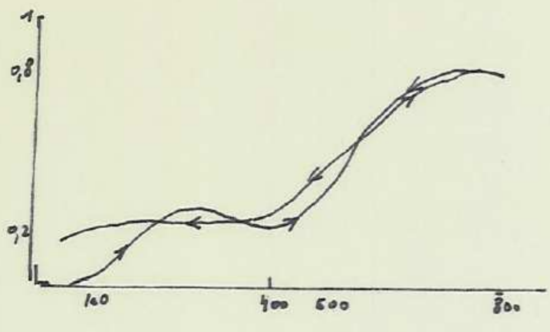

Influence du Rapport E/p

(dessin 14 d) [43]




contraction avec γ + q + NaCl.

(dessin n° 14 e) [43]




revêtement phosphoré

(dessin 14 f) [43]

- For [43] the impression expansion, the plaster dilates to 95%.
- The hygroscopic expansion is 1.2 to 2.2% (according to the silica used)
- The thermal expansion. The greater the silica, the greater the expansion. At a temperature between 600° and 800° it can contract by 2% (drawing 14c). The silica compensates for this contraction from which 1.3% is obtained with 75 M of crystallibility and 25% of

- other influential factors :
- water quantity (drawing 14d)
- chemical factors (Nacl) (drawing 14e)

◦ For ROUCOULE, the expansion factors are [41].
The relation $\frac{E}{P}$ and the spatulation
◦ MARMASSE [42] expresses these expansions in graphics.

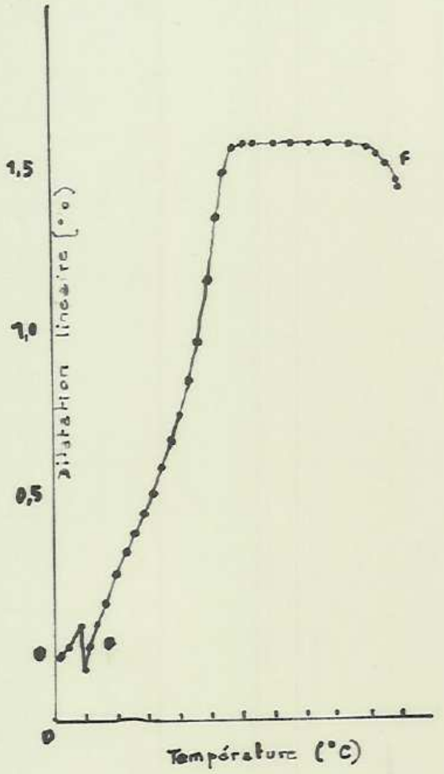
I – 2 – 8 – Dental alloys

During the cooling, a lot of shrinkage is produced [16] which is compensated for by the normal expansion of the coating: the average value of the shrinkage is 200 µ (hygroscopic : expanse of 180 µ). Without going any deeper, we see therefore that there is a lot of shrinkage between the hot and cold states.
For the stellites, the contraction would be around 2.3 [5]. We compensate for this by the thermal or hygroscopic expansion [31].
For certain alloys, the coatings have their secret (too) well guarded by the manufacturers (drawing 15a). Drawing (15b) shows the various expansions.

I – 2 – 9 – Dental amalgams

There are two kinds : spheric or traditional [42 to 45].
The ADA sets a dilation of 0 to 20 µ per centimeter.

But this phenomenum is not so simple; an amalgamation represents a state that varies with the temperature, which makes it fragile with age. A study of rays allows us to translate the classic expression [47] of the expansion of an amalgam impression.




Expansion thermique d'un revetement lié à la silice

(dossin n° 15 a) [31]

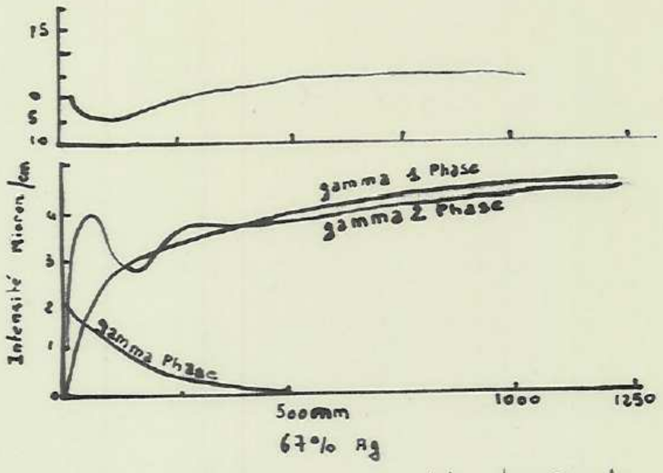
| ALLIAGE | RETRAIT de COULEE (%) |
|---|---|
| I | 2,24 |
| II | 2,23 |
| III | 2,14 |
| IV | 2,15 |
| V | 2,13 |

Retrait après coulée des alliages dentaires cobalt-chrome

| DIAMETRE de la BARRE FONDUE (mm) | RETRAIT de COULEE (%) |
|---|---|
| 3,18 | 2,25 |
| 6,36 | 2,53 |
| 9,54 | 2,39 |

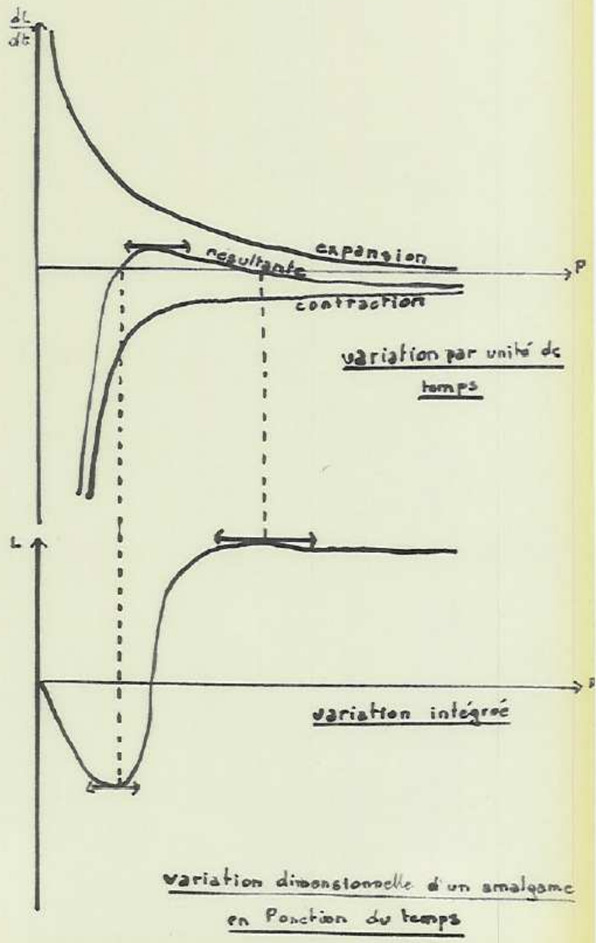
Influence de la superficie sur le retrait après coulée

(dossin n° 15 b) [31]




stabilité dimensionnelle, evolution des raies des differentes phases au cours du temps alliage en poudre (67% Ag) + mercure

(dossin n° 15 c) [44]




variation dimensionnelle d'un amalgame en fonction du temps

(dossin n° 15 d) [44]

BLANC BENON offers us more details and differentiates the phases (A. Spheric) [44] (see drawings 15 c-d-e).

The remarks are identical for the copper amalgam.
The growths are linked to two phenomena [44]: contraction and expansion, which theoretically must never be dissociated.

### I – 2 – 10 – Obturation cements

#### I – 2 – 10 – 1 – Silicate

Obturation cements allow an esthetic restoration in current practice, but they present huge inconveniences: pH acidity : 2.3 to 5.2 [31] and use in oral humidity which provokes the percolation phenomenum [48], (rubber dam almost never used).

The dimensional variations are very large, usually in the direction of a retraction [31].

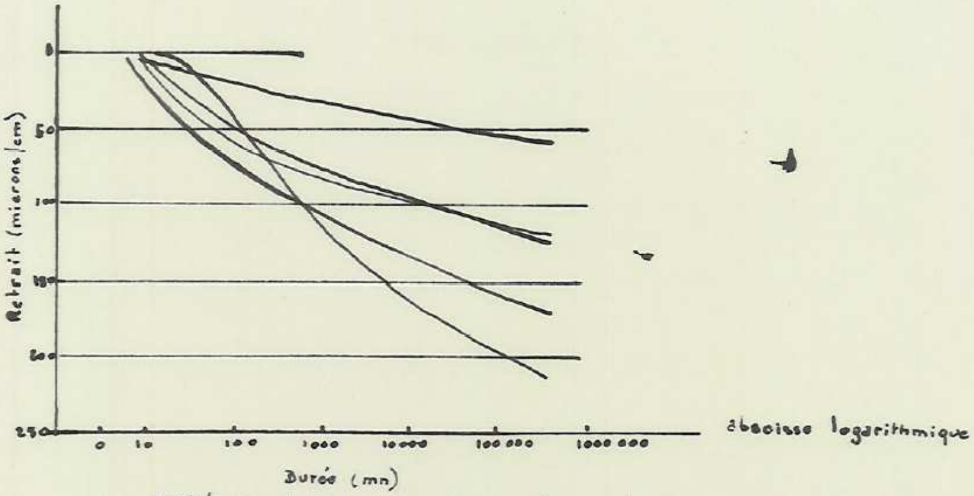
For NALLY, the slow polymerization after the impression is responsible for this contraction. The absence of recurrence (optimistic) comes perhaps [5] from the fluoride and the oral environment, 1% contraction in R Buccal – 0.2% contraction in R Nasal. This is due to the irreversible character of the silica gel.

#### I – 2 – 10 – 2 – Resin

A great power of contraction (see impression resin).

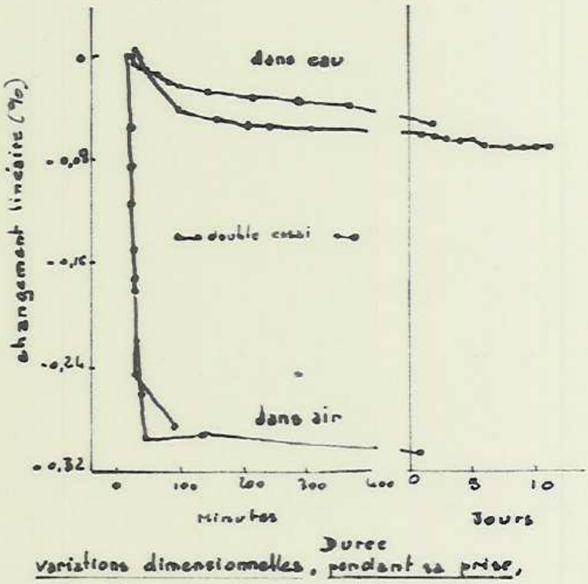
#### I – 2 – 10 – 3 – Composites

These are resins with particular components [46] having the property to retract less. The resulting contraction on dilation is not as large, but for BLANC BENON [45] the percolation is not avoided.



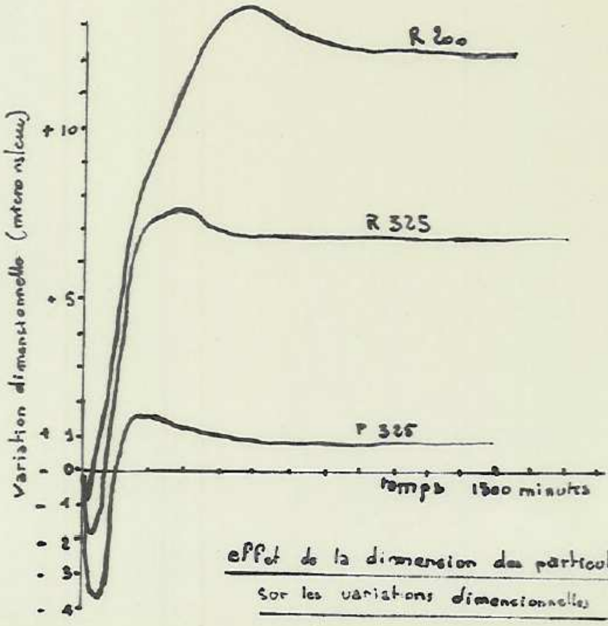

Variations de dimension des ciments au silicate dans l'air, après la prise

(dessin 16a) [31]




Variations dimensionnelles, pendant sa prise, d'un ciment au phosphate de zinc

(dessin 16 b) [31]




effet de la dimension des particules d'alliage sur les variations dimensionnelles d'un amalgame

(dessin n° 16 c) [31]

I – 2 – 11 – Sealing cements

I – 2 – 11 – 1 – Zinc phosphate cements [31]

Either for a film: linear stability of 0.08% i.e. 0.08 μ (very weak) (drawing 16 b).

According to NALLY, one can observe a contraction after laying it down from 0.3% in the open air and 0,5% in water, so these values are negligible.

I – 2 – 11 – 2 – Copper cement

See zinc oxide cement [31].

I – 2 – 11 – 3 – Zinc oxide and cugenol (?)

Remark :

ROUCOULE [18] recalls his results of the sealing cements. The setting contraction is 0.004% (in a humid environment), 0.28% (water).
Fortunately, the space is very small.

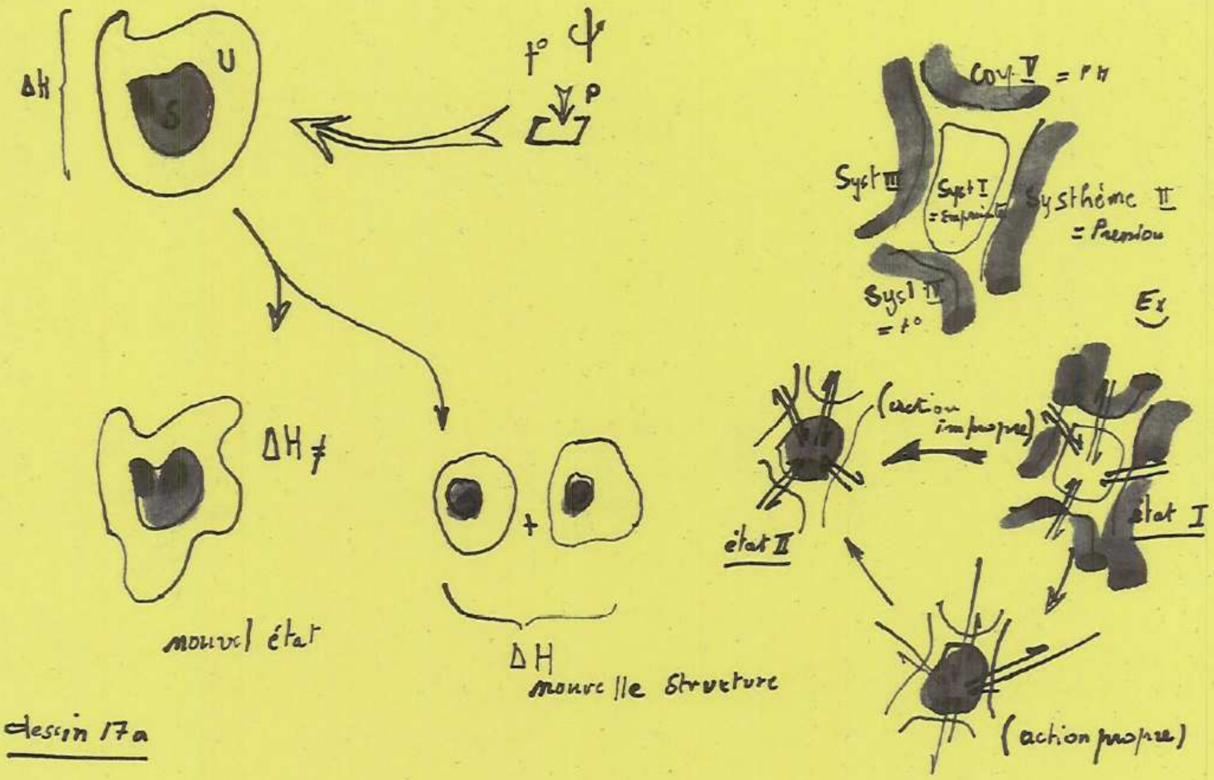
- We will not discuss here the precision of the articulation control materials (see outside studies). The precision is from 150 μ to 5 μ [16].

- The measurements: definitions
- 1 m : $10^3$ mm = $10^6$ microns or = $10^{10}$ Å
- syneresis: separation of the liquid from a gel
- percolation: absorption, rise of water

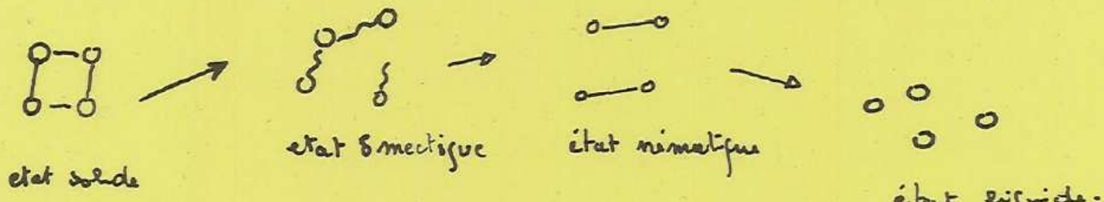
## I – 3 – PRECISION TENDENCIES

We have just enumerated the degree of dimensional variation of the substances used in dentistry.

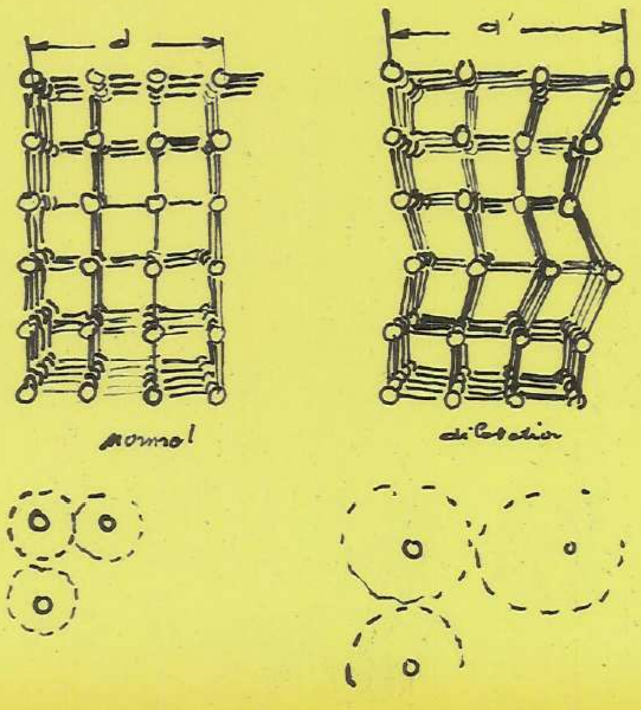
This factor cannot be treated in the standard way because it is part of a given whole, "The Chosen Substance", in a given stage




dessin 17a




dessin 17b




dessin 17c

I – 3 – 1 – Why is there dimensional variation ?

A system (for us the group of substances such as air, impression paste, etc..) possesses a total or entalpic energy.

$$H= U +PV$$

It is the internal energy, a definite value.
Values U and H cannot be measured because there are too many factors involved. We only measure variations of these values.

$$\Delta H=\Delta U + P\Delta V$$

(variations : exergonic - Δ H and endergonic + Δ H)

According to KALOIRE, the usable energy of a system is only part (Δ F) of this system. It is called free energy. The unusable fraction is called entropy (ΔS). “S” represents the amount of energy tied to the electrons and is itself linked to the probability of the electronic movement. It is a universal function of the probability state of a system.

According to BOLTZMANN’s data :

$$S = K \log p+c$$

And according to CARNOT :

$$dS \geq \frac{dQ}{T} \quad \text{(irreversible process [51])}$$

It is our inability to coordinate the molecular movements that makes so much energy unusable.

It should be noted that the actual position of the probability of the values linked to entropy follows an oscillatory value which corresponds to the molecular oscillations. This is important because a large oscillation can reach a change in the conditions [50].

Therefore, a system’s entropy appears as a probability factor which defines the internal order of the system.

For a characteristic molecule there is no entropy at –273°C. It corresponds to the accumulated energy in the form of rotation, translation, vibration or electronic phenomena… This energy is even greater if the system is more complex and if the atoms and the molecules are more numerous and deformable.

So this S energy can vary considerably during a chemical reaction because it depends on a number of possible arrangements of the molecules and on their various internal distributions, while the total energy remains unchanged. For each macromolecule the role is considerable [49].

The macromolecule plays a role in every possible form of the molecular arrangement, the molecular composition, the number of atoms, the grouping, the ionic and atomic structure, temperature and influences the physical condition.

This energy does not produce any work and is very susceptible to be influenced during a reaction.

The MAYER and JOULE principle

"When during dilation a substance produces a positive work on the exterior substances in contact with it, a certain amount of heat is lost.

Inversely, if a substance contracts and if the exterior substances exert a positive work on it, a certain amount of heat is generated.

In both cases, there is a constant relation between the amount of work produced or absorbed and the amount of heat lost or generated. This relation is independent of the substances brought into play".

I – 3 – 2 – Departing from this data

It seems to me essential to state the first "principle of precision" which perhaps can be summed up as follows:

Precision does not exist in the absolute, it is related to a condition (EINSTEIN) and is only a function of a system's condition, that is to say of its entropy, which is only a probability of fixed existence.

On a higher scale, if we disregard the relativity of things and use an average value of S in the probability, and if a system's own internal energy does not vary, the precision will be such that there must be a

$\Delta H = \Delta G + T\Delta S$ with no variation between two periods - $\infty$ and + $\infty$ .

This would assume that our system (impression) is independent of other systems (different T and P) which is false. This, then is the second "principle of precision" and represents the dimensional variations. For example: exchange of temperature, different pressures

To sum up, our imprecision is linked to our own action, this way we modify the actual structure of a substance $\Delta S$ whatever action is taken (a change in condition or a chemical reaction).

$$\Delta H = \Delta U + T\Delta S$$

But the imprecision of our action is equally due to how an unstable thermodynamic system reacts with the other systems (as it is the case with our paste in the surrounding atmosphere) (drawings 17 a-c).

So we find ourselves with a double imprecision: characteristic (by our action) and uncharacteristic, so-called characteristic by relation (by the inter-phase of the systems in situation).

### I – 3 – 3 – Entalgic atomic entropy ?

What is a solid in thermodynamics [51] ?
A solid can transmit forces (≠ gas) and appears crystallized (vitreous: a high-viscosity liquid).
It can present several stable forms at pressure P (allotropy). The transition from the liquid state produces an amorphous isotropic structure. This transition is done according to: (see drawing 17b).

CLAPEYRON's formula gives the amount of heat needed for melting :

$$L_f = T(V\rho - V_s)\ \frac{d\rho}{dr}$$

$L_f$ = latent fusion heat

I – 3 – 3 – 1 –

EINSTEIN's solid with a constant volume in non-quantum theory [51]
A group of moderately fixed atoms which travel in little movements around a position of balance.

We can consider them as independent and speak of drawback forces and not interaction forces. The potential energy of each oscillator is therefore that of the interaction energy. (They are not really independent oscillators).

The internal energy (the internal heat) in transition

$$U = C^2Nm + \frac{2N\theta}{K} = C^2 \, Nm + 2 \, R\theta$$

depends only on the temperature (oscillator N), the only variable in condition.

I – 3 – 3 – 2 – Same in quantum theory [51]

Calculation with a spatial quantum energy oscillator

$$E = hV \, (n+\frac{3}{2})$$

We know only the total energy. It is not possible to separate the internal heat. Therefore, we cannot determine $\theta$ [51] gives the value of

$$U - U_T$$

I – 3 – 3 – 3 – DEBYE's drawing

The atoms are not alone and isolated. There are interactions between them. (There is a propagation of speed waves depending on the direction and the frequency).

I – 3 – 3 – 4 – DEBYE's dilation

"The displacement of the middle position is slightly proportional to the oscillators' energy. Because the "ge" is so small, this energy is not very different from that of the symmetrical oscillator."

The drawback forces of the solids are not exactly proportional to the elongation. The displacement of the middle positions is translated by a dilation that is proportional to the energy and, therefore, to the temperature [51 and 53].

### I – 3 – 3 – 5 – Conclusion

The dilation [1.3.3.4.] as with any change in condition [1.3.3.], is translated by a variation that is proportional to the energy, and therefore to the temperature. This variation in energy is due to the fact that atoms oscillate (drawing 17o), quantify themselves and are dependent on each other. Even the drawback forces [1.3.3.4.] are a function of the energy. Therefore, mathematically the condition of a system is tied to its energy which in turn depends on the temperature.

Precision is theoretically impossible unless:

$T = -273°C$ when

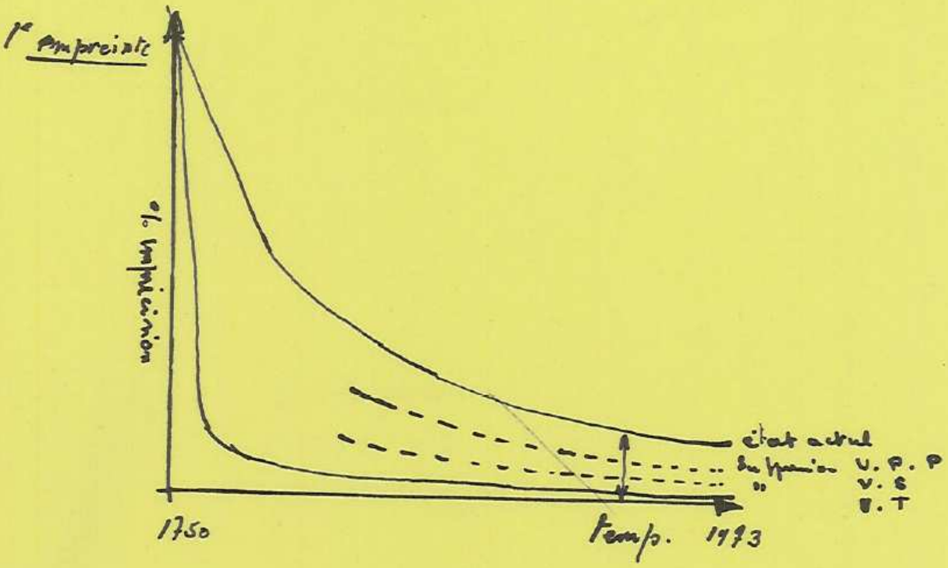
$$\Delta H = \Delta U$$

The molecular vibrations, etc… indicate that, even in a stable system at a temperature $T_1$, precision is only a probability of precision (tied to the probability of atomic presence).

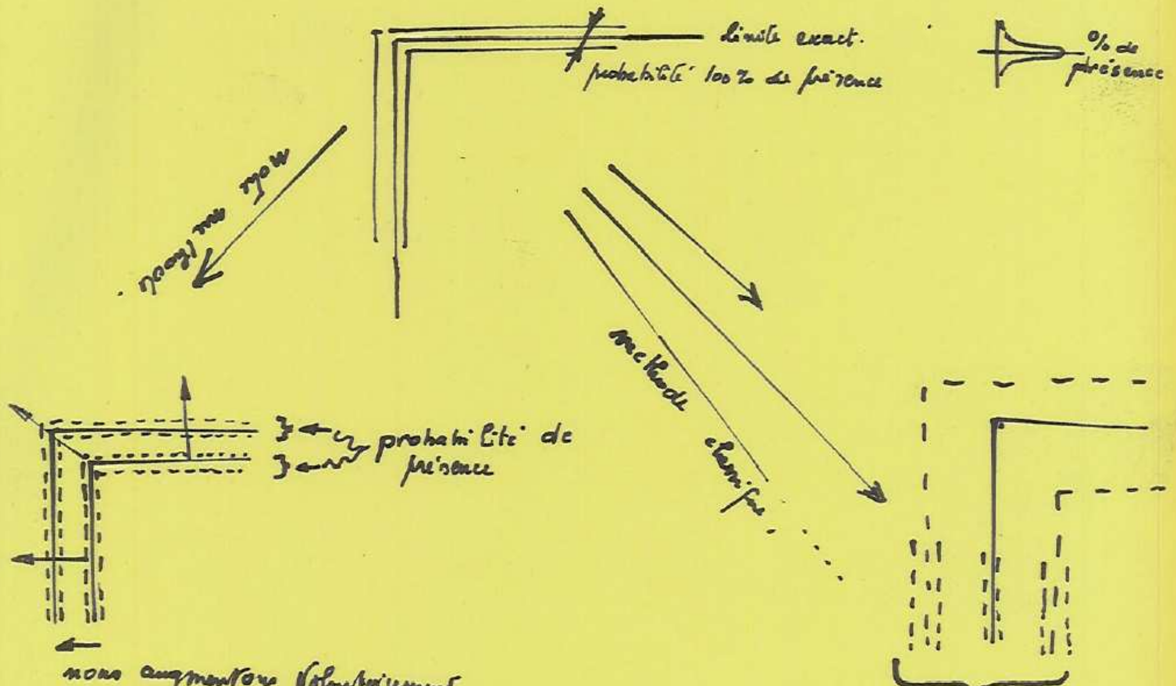
### I – 3 – 4 – Where is precision found ?

No where. Precision is relative and probable. To come close, we must exclude all energetic modifications from the system and any possibility for loss of data. To do so, I propose a method in this thesis.

Until now [27], precision was tied to practical observation and practically measured [52]. Almost the entire beginning of the first chapter proves this. We would limit ourselves to considering spatial variations [conclusion of 27]. We would classify materials by action category [16 to 29], by action zone [conclusion of 29], and by physical environmental factors [4]. They all lead to sometimes very brilliant manipulations and we benefit from this everyday in current practice. For this we thank Mr ROUCOULE in particular [16]. However, the imprecision is more than a simple “algebraic addition of dimensional variation” [16]. It is the act itself of all energy variation. One hundred percent precision exists. It is a probability of presence. The tooth itself does not escape this condition. It is desirable (here we disagree with ROUCOULE [16] because it can be reduced.




dessin 18a.




probabilité de présence

nous augmentons volontairement notre mesure 100 % exacte avec une probabilité de présence appliquée.

ex. 100 % → 105 %.

la probabilité de présence reste confinée à la vibration moléculaire mais si l'empreinte fait 105 % elle a fait avec une précision 100 % ± x

On ne peut affirmer la position exacte l'imprécision (5 %) s'ajoute à la probabilité de présence

dessin 18b

Here ROUCOULE confuses precision and imprecision. Precision is always 100% probability but a 95% precision can be 100% probability. If, for example, mathematically and deliberately I reduce the measurements to 95%, the probability of presence is still 100%. By our classic methods, it is on the 100% probability that we act, but not on the measurement reduction in a mathematical manner with a 100% probability. In our case, the precision is the imprecision in ROUCOULE's case. Therefore, yes, the probable precision of 100% can be mathematically modified from 100 to 0%. The purpose of my study is to be able to use this character belonging to mathematical science and apply it in this field.

### I – 3 – 5 – What are the various imprecisions ?

I speak of imprecision, that is to say, of the unknown x% precision in the probability of presence [1.3.4.].

I classify the imprecisions in three classes or variations: primary, secondary, tertiary. Each class is subdivided into two phases: major phase and minor phase.

#### I – 3 – 5 – 1 – Primary variation

It can be characteristic or uncharacteristic, depending on whether it is the consequence of our action or that of the system in contact.

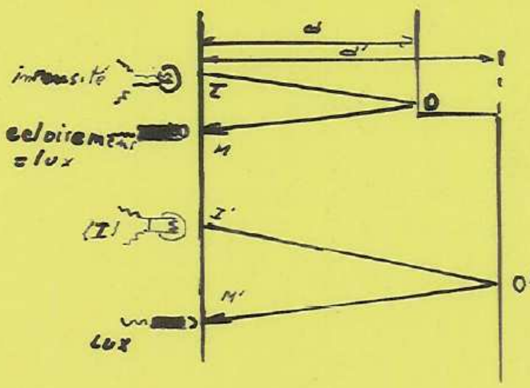
a) Primary major characteristic variation

- change in condition (liquid – solid)
- change : in molecular composition, the number of atoms
  complexity of the group (chemical R)
- allotropic change in a condition (in Ag)

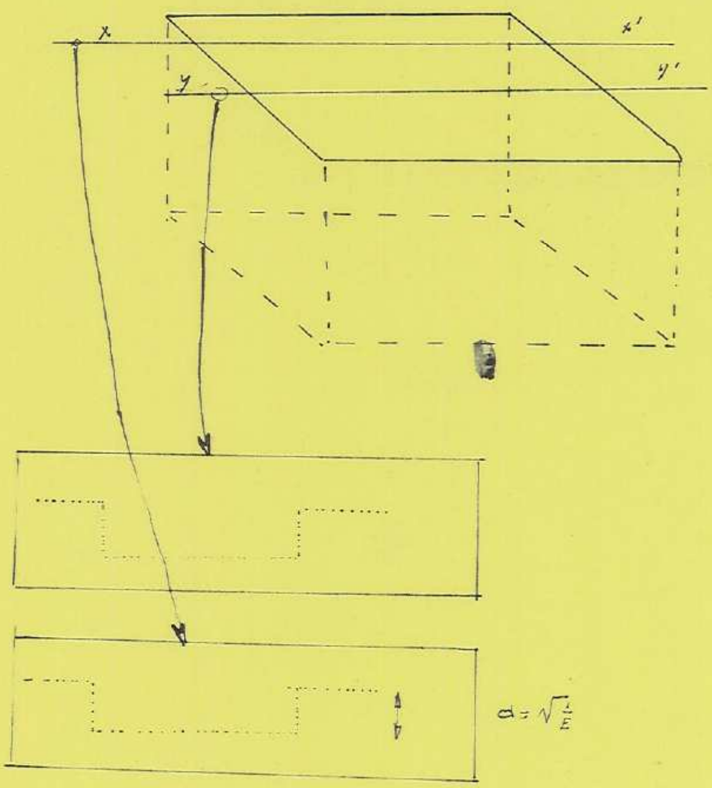
We can do nothing because by our action we are responsible for the variation $\Delta H$.

b) Primary uncharacteristic variation

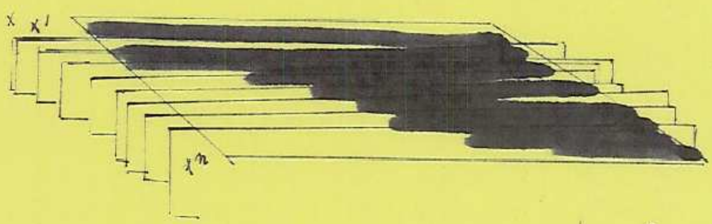
Thermal exchange, from which we have the energy variation with the other systems.




dessin 19 a




dessin 19 b




dessin 19 c

We can do nothing because these are the consequences of the thermodynamic imbalance that we create.

<u>c) Primary minor characteristic variation</u> {same, but localized
{to a zone in
d) <u>Primary minor uncharacteristic variation</u> {space

The result is distortion [5.6].
They can be classified [52] : (these V.Pm)
- destruction of form : (cylinder, diabolo, banana, comma, tendril)
- conservation of form :
  error in <u>dilation</u> : linear contraction
  diametrical contraction
  error in <u>rotation</u>

<u>I – 3 – 5 – 2 – Secondary variation</u>

<u>a) Secondary major uncharacteristic variation</u>
We can do nothing because the material is responsible
- action done during the impression (contraction of the impression)
- products react with the object (drawing)
- immediate water loss
- temperature, pH, atmospheric pressure of the mouth

<u>b) Secondary major characteristic variation</u>
- Our method is not rigorous (spatulation, time, percentage, boiling, impression holder, liquid film which remains, pouring too late, insertion, uncertain anchoring and withdrawal, acrobatic wax sculpture).
- the proposed method is bad one
- outdated products

<u>c) Secondary minor uncharacteristic variation</u>
- superficial loss of water at the local level
- contact
- pH in oral atmosphere
- pH of galvanoplasty…

d) Secondary minor characteristic variation
There are all kinds of homogeneity defects.

I – 3 – 5 – 3 –

a) Tertiary major uncharacteristic variation
- respective dilation (coating in relation to the metals)
- individual impression holder in relation to the paste
- dilation of the copper (ring)
- differences in production of the same product
- patient who moves…

b) Tertiary major characteristic variation
- number of models made
- our psychological influence on the patient
….
This way in our manipulations, the imprecision is uncontrollable (we only know the energy variations) and vitally important. We must therefore suppress additional factors and control the precision as much as possible.

I – 3 – 6 – Eliminating different variations

By the classical methods, it appears to me difficult to reduce tertiary-type variations, even secondary uncharacteristic ones. However, in the current conditions of our most advanced theoretic knowledge, there is no possibility for the primary major and primary characteristic and uncharacteristic variations to be suppressed.

Therefore, we can speak of a kind of “asymptotic of the precision” (drawing 18a).

The only means then is to reduce the data, not by modifying them as do the laboratories (and not the researchers), but by suppressing them. This can appear absurd but I will explain with more details in the coming pages.

If I take the definition of the word “precise”: “that leaves no place for uncertainty, precision is the character of what is clear and exact”.

The precision of a measuring instrument is as exact as it is sensitive, more mobile, more reliable in reading, more faithful, and finally more precise [54].

### I – 3 – 7 – Chosen values for these eliminations

#### I – 3 – 7 – 1 – Biological measurements

Man uses language to express himself [55-56] in speech or in writing. To express a qualitative value, for example the length of a part to cast, we attach the concrete reality (the part) to an abstract notion (its size). We base our argument on these abstract notions on the S I (International Unit System).

#### I – 3 – 7 – 2 – Base unit

What is the base unit of a length ?
It is the meter. But it does not interest us. We know that in dental surgery in $10^{-5}$ m, the lowest sub-multiple of S I meter is around $10^{-10}$. As we now know that the most important thing is to know the greatest precision even if it means reducing it mathematically according to our own will. We can affirm that we can get around these orders of size.

#### I – 3 – 7 – 3 – The phenomenum in biology

The extrapolation of exact measuring methods into biology constitutes one of the important problems in modern science.
In fact, this elimination would allow the systematic application of the mathematical principle to the study of biological phenomena. It allows one to treat the phenomena with a rigor comparable to that of physical science.

To come back to registering a biological phenomenum (biological positions for us), we use instruments which transform it into an easily measured response. This response can be read directly or recorded [55].

### I – 3 – 7 – 4 – Theoretical plan for a measuring instrument

This system is composed of one sensitive part, an amplifier, a recorder and a linking system.

The sensitive part is put in contact with the phenomenum to be measured. Often the measured energy is transformed into another form of energy, usually electrical which can be transmitted, amplified and recorded more easily than the initial energy [55]. This transduction is produced by the transducer, generally the sensitive part itself.

The amplifier system or recorder consists of a scale and a needle in motion.
A transmission system connects the recorder to the transducer.

### I – 3 – 7 – 5 – Errors

To avoid errors in biology measurements so that the values are precise and not unquestionable (relativity), the device must be functionally isolated from the biological system. In other words, it must measure without modifying.
We must use as precise a measurement as possible.

The measurement standard can be defined as an object which represents the unit of size, for example [55]. Currently, the mathematical unit of the standard is the length corresponding to the transition $2\rho_{10}$ and $5d_5$ of the KRYPTON atom 86 (rare gas from the air) = 165.763,73 in the void. (There is a mathematical tendency toward 0 to suppress the interactions).

The other radiations used as the standard are radiations of the gas laser and mostly the line $6328.10^{-10}$ m of the neon helium laser. We need a stabilized monomode laser (commercial types exist) to measure the air. We must divide by the index 1.00028. (This is the only precision problem).

I – 3 – 8 - Our plan towards precision

The information signal can use four energetic supports (electrical, pneumatic, hydraulic and mechanical) and exists in two forms (analogical and numerical). The measurement converters will adopt these signals between them.

I – 3 – 8 – 1 – Analogical numerical converter

The sizes are continuous or analogical and are transmitted numerically. These are various numeration systems (decimal, binary, decimal side D.B.D.C.B.).

The method is done either by successive scanning or by integration.

I – 3 – 8 – 2 – Numerical analogical converter

It is the opposite or decoder.

I – 3 – 8 – 3 – Suppression of the major and minor primary variations, characteristic and uncharacteristic

Let us return to the definition of the major and minor primary variation change of $\Delta H$. System entalgy.
To avoid it in our system, we refuse to set any chemical or conditional variation. If we have to, considering that we are able to know one (simple variation), we need only be aware of it (personally, I am against this procedure).

To replace it, we use the least sensitive and most precise energetic support:
$\lambda$ = wavelength

I – 3 – 8 – 4 – Secondary major and minor uncharacteristic variation

The idea is to avoid influential factors. For this, we provoke an immediate conversion of our phenomenum (holography).

To avoid time factors, we use an unmodifiable information energetic support (theory related to the time that we send). This is the optical ray (laser).

-Secondary major and minor characteristic variation

We use a rigorous data support which is independent of the time and of us. These are numerical supports (Mathematics). We suppress human manipulations (buttons). Physical science.

I – 3 – 8 – 5 – Tertiary major, minor, uncharacteristic variation

The related interactions (paste in relation to the impression holder) are suppressed. Obviously, storage will be done into mathematical values (video recorder, hologram…). The patient factor is limited to the time of the propagation of the ray (physical factor).

- Tertiary major, minor, characteristic variation

The duplication is done in mathematical values, and therefore fixed in unlimited number.

## I – 4 – OUR METHOD

The first problem for us is the transformation into numerical of the analogical size by a converter.

I – 4 – 1 – Our analogical size is essentially the volume

We measure a difference in distance.
We look at the theorem [57].
If two light intensity sources I and I' produce the same illumination on a screen placed at distance D from the first source and D' from the second, the intensities are proportional to the square of the distances on the screen (drawing).

So an illumination produced by both sources on the screens I and I' which are defined as illuminations produced at the unit of distance, we have logically,

first source : $\frac{E}{I} = \frac{1}{D^2}$

second source : $\frac{E}{I'} = \frac{1}{D'^2}$

thus : $\frac{I}{I'} = \frac{D^2}{D'^2}$

In theory, each surface unit receives a light intensity which is inversely proportional to the square of the distance separating the illuminated surface and the light source [58].
As the illumination of the surface is proportional to I (drawing 19a)

$$\frac{E}{lux} = \frac{1(candle)}{d2(meter)} \qquad (3)$$

r = surface ray
j = unit of I
I = intensity
d = distance

Based on the formula (3)

$$d = \frac{I}{E} \qquad (4)$$

This means that any light beam carries its distance information according to the intensity at the point of contact on the screen.

Let's study the reception of this analogical value which is the distance but more exactly the intensity resulting from the distance (drawing 19 b).

It is evident that the received intensity in M is higher than that received in M'. It is possible, both mathematically and at the level of the photoelectric cells in the diagram (formula 3), to extract the values of d and d' (angular correction done).

<u>I – 4 – 2 – Analogical converter</u>

We understand at the start that our numerical analogical converter will be formulated as needed in binary decimal D C B and have electronic signals.

In the mouth, you tell me ! We see a scanning of the "Region to be measured". Somehow we obtain a group of successive sections (drawing 19b) which, when put next to each other (drawing 19c), form a total volume. This is what I call the "optical volume" which is in fact a "mathematical volume" obtained from electrical data, but it is the mathematical function of optics (formula 3) which allows me to formulate this idea (see chapters 6 and 7, drawing 20a).

### I – 4 – 3 – Negative crystallization

In order to crystallize my negative in the shortest amount of time so that the time factor does not come into play (precise impression conditions), I use holography which again justifies the use of laser. Holography is based on the principle of interference and allows us to reason not in microns but in wavelengths. The precision is therefore absolute (drawing 20b).

Why the hologram ?
I chose the hologram because I can do the crystallization literally in a flash.
Not only is the time factor removed, but the hologram is the only thing that offers me a three-dimensional scan in two dimensions (see chapter 5).
Without moving any object related to the converter, the analogical numerical converter can easily analyze the intensities and, therefore, the distance in all the possible cases (chapter 7 – drawing 20c).

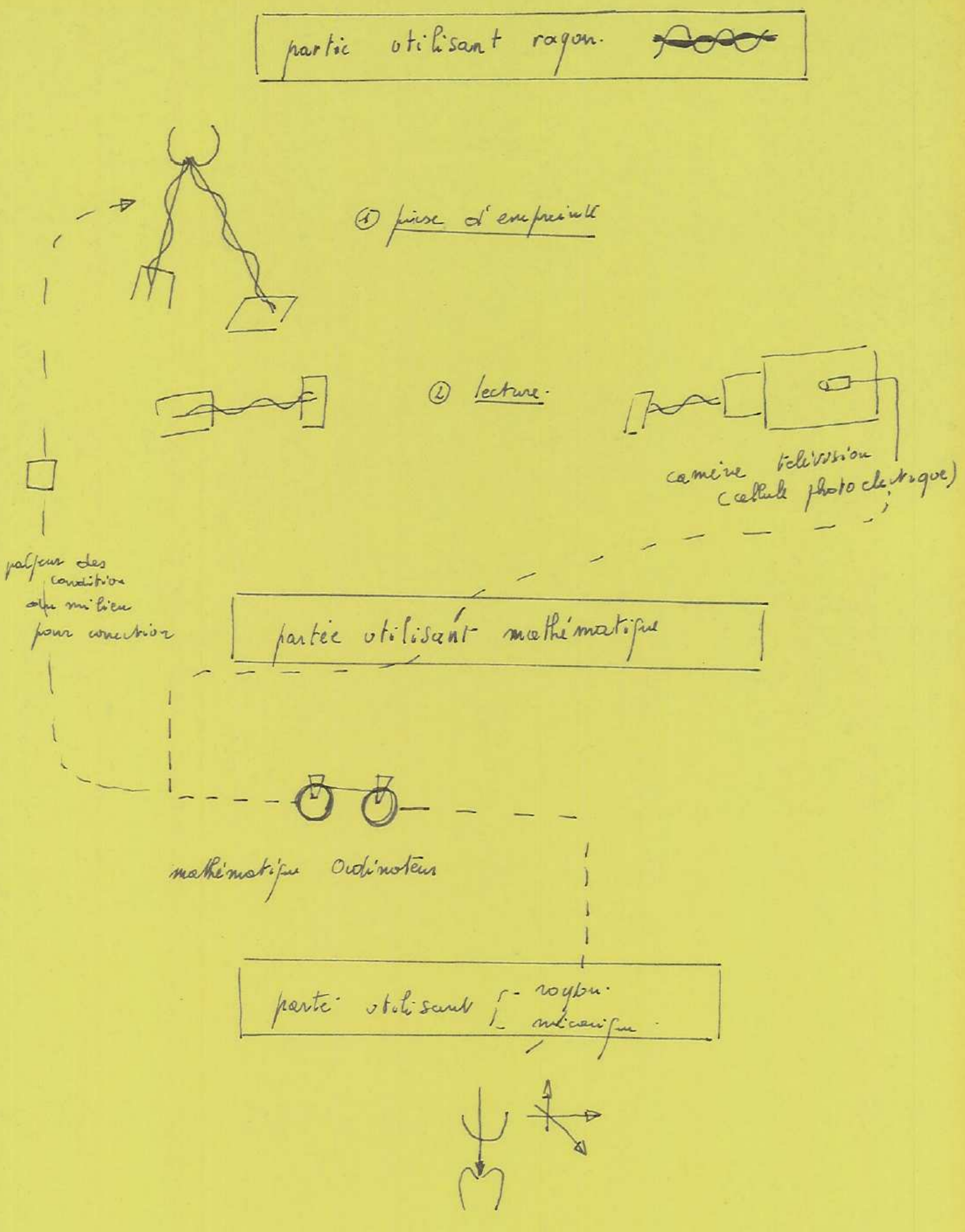
### I – 4 – 4 – Laser and biology

I chose the laser ray because it allows me to crystallize the impression (negative crystallization), but also because of its precision and its qualities (coherences…). It allows me to remain in almost pure mathematical bases (denial of approximation) (chapter II).

One could object to its action on the tissues. On the contrary, it is an advantage that I will study in detail in chapter III.

### I – 4 – 5 – Storage (drawing 21 a)

Storage of impressions can be done using three processes: holography and computer terminal or, more easily, the video recorder. These procedures are almost unalterable and here, again, the precision in the n samples is exempt from any variation and imperfection (chapter IX).


partie utilisant rayon.
① prise d'empreinte
② lecture.
camera télévision
(cellule photoélectrique)
palpeur des conditions du milieu pour correction
partie utilisant mathématique
mathématique Ordinateur
partie utilisant
- rayon.
- mécanique.

dessin 20 21

I – 4 – 6 – Why the computer ? (drawing 21b)

It is not compulsory but according to my method as long as a practical implication of chapter IX will be satisfactory: any build-up will be practically realized.

The computer allows storage and direct sculpting by reference or by need.
Direct or inverse sculpture. It is the logical end of everything; its principle is simple subtraction.

I – 4 – 7 – Analogical numerical converter

It is the decoder: a numerical size materialized in a memory will correspond to an analogical electronic signal (current or tension) which is proportional to it [55].

A sculpture of a part will correspond to this analogical electronic signal according to different procedures: the mechanical (micro-sculpture) procedure and the optical (ray) procedure.

Instead of taking a distance, it is the stored distance in the signal that the head of the sculpture perforates at a dimension d.

We thus avoid any dimensional change in the material by suppressing all imprecisions of the wax, the coating and the sculpture.

The $\Delta H$ is fixed no matter what the action, whence the rigor (probability of precision) of the method.

The granulometry is freely chosen and not according to the casting possibilities. The sculpture is theoretically chosen.

## I – 4 – 8 – Conclusion

We will use the standard (optical) unit for impression. We will set the wavelength in (hologram) units of measure. Here again, we analyze it very rigorously in this same value (scanning). Then we store it in numerical values (VCR). From this storage with a chosen reference (computer), we build up or rather we sculpt the positive.

To conclude, we suppress the imprint, all forms of the positive impression, all forms of sculpture, all of which depend on the prosthesist's experience.

The coating, the casting and its cleaning become useless.

By applying the principle (MARMASSE) that "a well made amalgam is worth more than a bad inlay, but a good inlay is better than a good amalgam", the inlays are created in a precise and rigorous manner by this method…

Perhaps one day we will suppress the use of fillings in our profession.

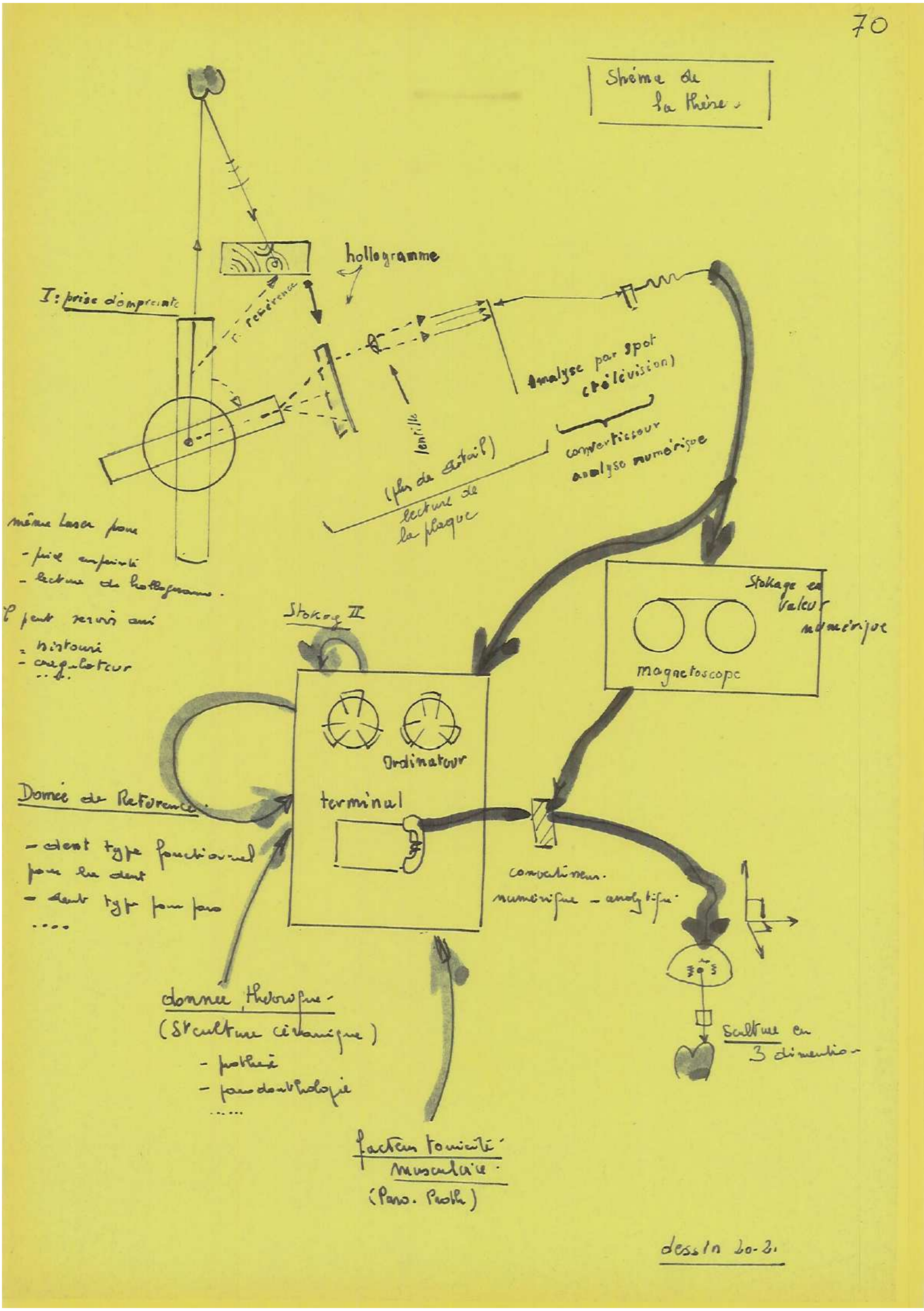
1°/ - In this chapter we explain that the classical methods in prosthetics, as in dentistry (amalgam), are imprecise and studying them demonstrates the disagreement among the various authors [1.2].

We explain why we believe that the cause of this is the energetic variation of the systems (that we use) and the importance of the number of factors which influence this variation. We define which for us are the variations according to the physical data [1.3].

Then we explain that the use of a simple system (laser + hologram + scanner + computer + milling machine) allows interesting results in precision and speed, because quantitative and not qualitative values are used.

2°/ Now we have the duty to explain what the optical impression is and why we chose to use the laser. The laser's properties explain our choice, we must specify them and, above all, justify them.

The atom will give us an answer, the double hypothesis of the quanta and of electro-magnetic is then explained in order to justify the exceptional qualities of the stimulated emission.


Shéma de
la thèse.
hollogramme
I : prise d'empreinte
référence
lentille
Analyse par spot
(télévision)
convertisseur
analyse numérique
(plus de détail)
lecture de
la plaque
même laser pour
- prise empreinte
- lecture de hollogramme.
Il peut servir aussi
- bistouri
- coagulateur
...
Stokage en
valeur
numérique
magnetoscope
Stokage II
Ordinateur
terminal
Donnée de Référence
- dent type fonctionnel
pour la dent
- dent type pour paro
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convertisseur
numérique - analytique
sculture en
3 dimention
donnee théorique
(structure céramique)
- prothèse
- parodontologie
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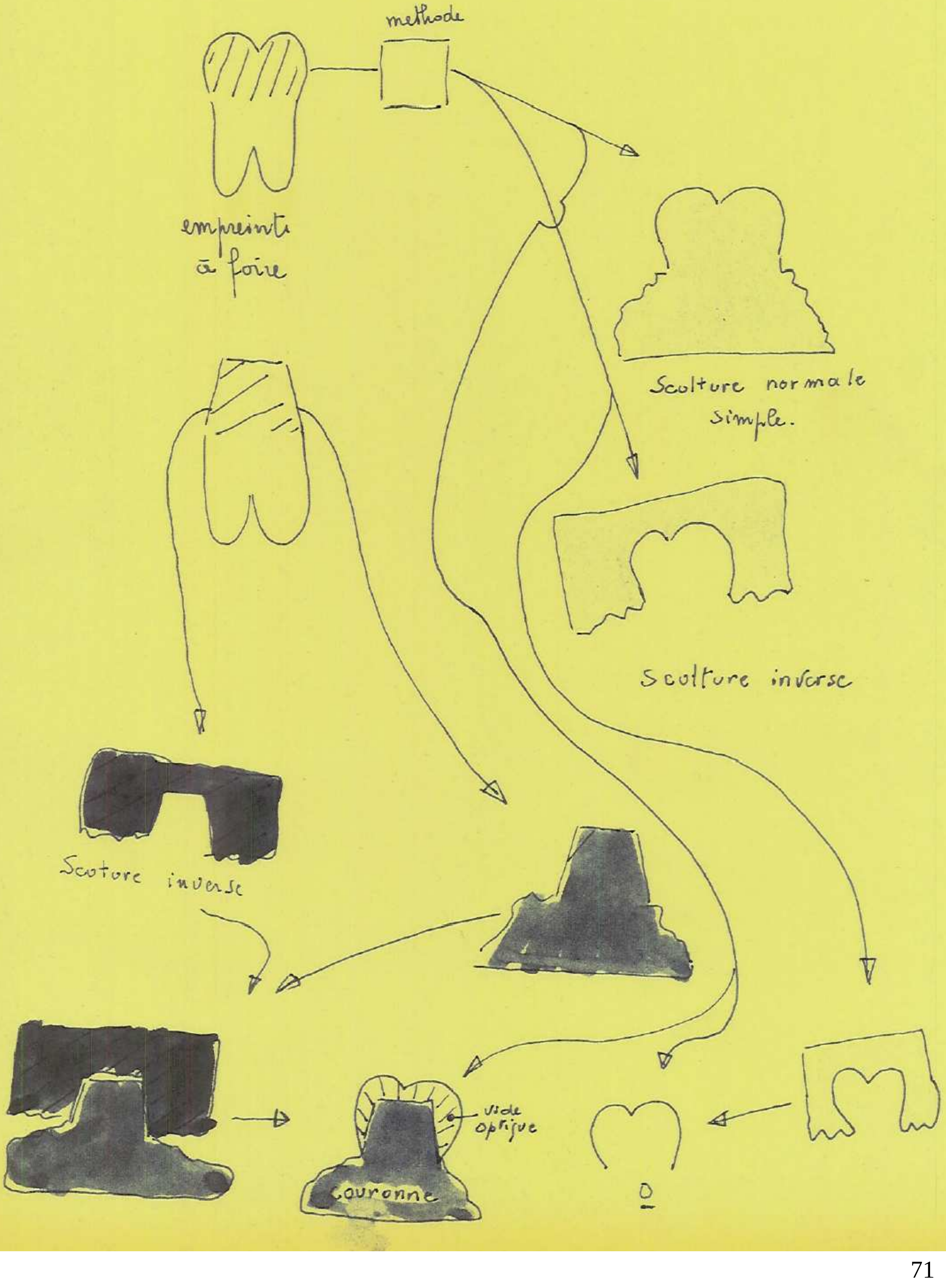
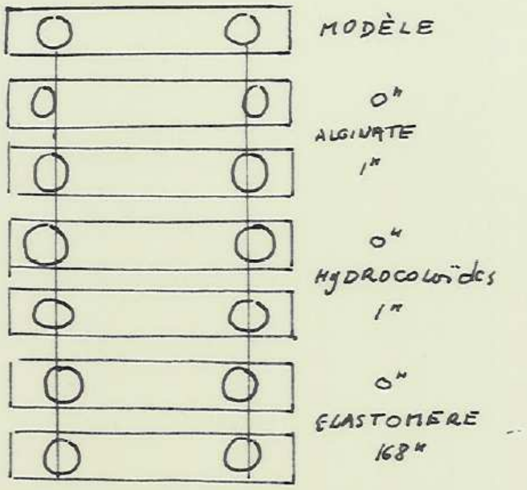
facteur tonicité
musculaire
(Paro. Proth.)
dessin 20-2.

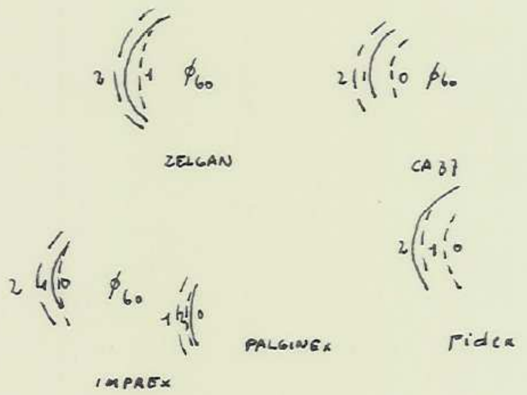
types de Scolture

dessin 22



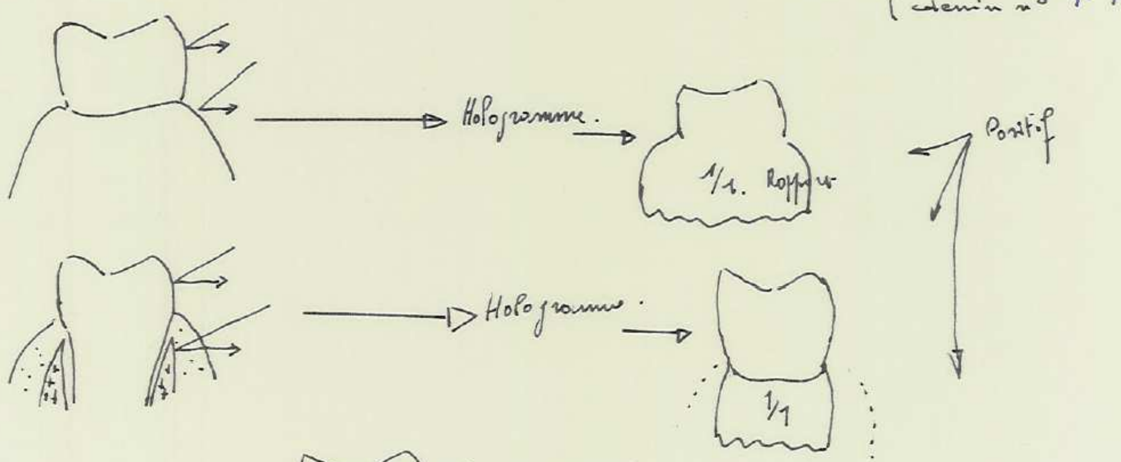



comportement des matériaux

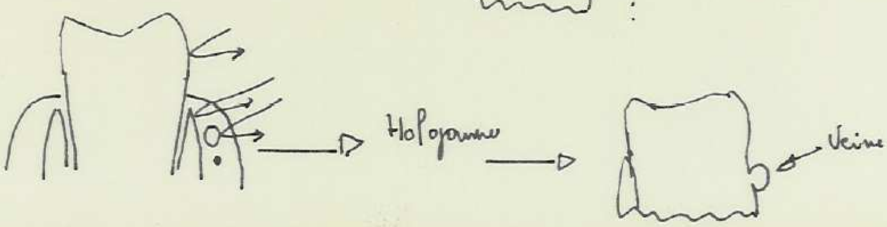



Variation de diamètres transverses

(dessin n° 7)




(dessin 22)



# THE LASER EMISSION

## From theory to practice

- HISTORY
- ELECTROMAGNETIC WAVE
- ATOM AND WAVE
- LIGHT WAVE
- ORIGIN OF THE WAVE
- LASER CHARACTERISTICS
- OUR CHOICE
- CONCLUSION

# CHAPTER – II

## II – 1 – THE LASER RAY / INTRODUCTION AND HISTORY

Before the famous ray was born, there had to be a half century of research. A decade was enough time for these applications to appear but there would still be many long years before it could fulfil all its promises.

What are the principles that one day led Professor Theodore MAIMANN and his laboratory assistants at the HUGUES AICRAFT COMPANY in PASADERME, California to see a perfectly parallel, impeccably monochromatic beam gushing out from ruby ?
(The Coherent Light as EINSTEIN predicted) [62]

" The emission of radiation by atoms can be achieved using two different mechanisms : the spontaneous incoherent emission and the induced coherent emission" [63]
This is what we are going to discuss.

Before going into the laser's conceptions, it seems essential to us in a dental surgery 2nd cycle thesis to explain the electromagnetic rays, the structure of the atom and its functions, and quantum mechanics, and from these data explain why the laser ray was chosen, the properties which interest us and the reason why we integrated it into our system.

To separate the laser ray from its theoretical, mathematical and physical data would make it incomprehensible.

## II – 2 – ELECTROMAGNETIC WAVES

II – 2 - 1- A light wave, as with the undulation of a cord, is a kind of periodic perturbation moving away from a source. The sizes of the electrical and magnetic fields vary. Since they do so at the same time, a simple presentation will be done later on [64] – (drawing 23 a).

II – 2 - 2 – A wave is characterized by four important sizes

Length – Frequency – Speed – Amplitude

- The wavelength is the distance between any two analogous points : $\lambda$
- The frequency is the number of waves which pass through a given point in 1 second : N
- The speed is the rate of propagation : C.
- The amplitude is the amount of oscillation.

II – 2 – 3 – An electrical and magnetic wave or electromagnetic is :

- very extended in wavelength
- the same in speed, 300.000 km/s as in

$\lambda = \frac{C}{N}$ or $v = \frac{C}{n}$ ( n = index of the environment). (1)

- the low frequencies correspond to the wavelengths and vice versa.

## II – 3 – ATOMS AND LIGHT WAVES [ 53 – 65 – 66 ]

All light is emitted by atoms.
Here are the principles that govern the absorption and re-emission of energy by the atoms. Electronic configuration of the atom.
The atom is formed from an electronic cloud surrounding the nucleus.
e= 4,77 10-10 UES
m=0.91 10-27 g
z=atomic number

II – 3 – 1 – The WIELS-BOHR model

This interpretation is based on quantum mechanics.
- the quantum theory :
An enclosed space at a certain temperature is dark in order to avoid any exchange. The radiation does not occur in a continuous manner (fed by an oscillating circuit at the source), as in the case with a radio wave, but by small

bundles of energy (like bullets from a machine gun). This is quantum energy :

W= hV (2) $V=\frac{C}{\lambda}$ (3)

The carrier of this quantum is a particle without mass called a photon.

II – 3 – 2 – BOHR's postulate [53]

This model uses the quantum theory (Planck) [72 - 73].

POSTULATE 1 – The atom is stable, in other words it does not radiate when the electron moves in well-determined orbits or "stationary orbits".
Kinetic moment of this orbit

$mvr = n \frac{h}{2\pi}$ (4)

POSTULATE 2 – When the electron passes from one stationary trajectory to another, the atom's energy undergoes an abrupt variation (electronic transmission).

$W_n$-$W_{n'}$ and an emission or an absorption of a monochromatic radiation frequency √ stated by the relation :

$W_n$-$W_{n'}$ (or E-E')=h √ (5)

where : h = is from Planck, √ = the frequency, v = the speed and m =the mass.

1) $W_p = \int_{\alpha}^{r} \frac{1}{4\pi\varepsilon_0} z \frac{e^2}{r^2} dv$ (b) (potential)

2) $W_c = \frac{1}{2} m v^2$ or $m\frac{v^2}{r} = m\ \delta = \frac{1}{4\pi\varepsilon_0} z \frac{e^2}{r^2}$ (7) (kinetics)

As $W = W_p + W_e$ : $\boxed{W = \frac{-1}{8\pi\varepsilon_0} z \frac{e^2}{r}}$

Calculation of r (Broglie's)

$mvr = n \frac{h}{2\pi}$ (9)

$0_2$ (4) gives $v^2 = \frac{1}{4\pi\varepsilon_0} z \frac{e^2}{rm}$ (10)

thus $r = \boxed{\frac{n^2h^2\varepsilon_0}{Ze^2m\pi}}$ (11)

Calculation of $g = \frac{1}{\lambda}$

(8) and (11) give $W = \frac{z^2e^4m}{8n^2\varepsilon_0^2h^2}$ with {W = Fh

{$\frac{W}{h}=F=\frac{c}{\lambda}$

thus $\frac{1}{\lambda}=\frac{W}{ch}=\frac{mc^4}{8\varepsilon_0^2h^3c} Z^2 (\frac{1}{n1^2}-\frac{1}{n2^2}) = \sigma$ (12)

where $R^h = \frac{me^4}{8\varepsilon_0{}^2h^3c}$ (Rutherford's)

II – 3 – 3 – SOMMERFIELD's theory

This theory is the exact representation of the atom (characteristic of quantum numbers) according to our current knowledge (drawing 23 b).

II – 3 – 3 – 1 – Principle quantum number

The principle quantum number gives the size ( r ). It is the number of orbits and has a whole positive value.

II – 3 – 3 – 2 – Secondary or azimuthal quantum number

This number gives the form of the orbit.
The orbit can become elliptical.
This quantum number is characterized by a value (1) which is equal to : n – l.

II – 3 – 3 – 3 – Magnetic quantum number : m l

Due to the ZEEMANN effect.

$\rho \quad \cos\ \varphi = ml\ (\frac{h}{2\pi})$

*where ml is* $-l \leq ml \leq +l$

*thus* $n = 2 \rightarrow l = 0 \rightarrow 0$

*or*

$l = 1 \rightarrow -1$

$0$

$+1$

II – 3 – 3 – 4 - SPIN's quantum number : $m_s$

The electron spins while turning around the nucleus. For each value of m l, m s, takes the value $-\frac{1}{2}, +\frac{1}{2}$ (drawing 24).

I – 3 – 4 – Undulatory mechanics

II – 3 – 4 – 1 – Louis de BROGLIE [69 - 70]

The BOHR-SOMMERFIELD theory is in some way true because it allows to predict with precision the level of energy of the $H_2$ atom.

But, besides appearing artificial and over-added to the concepts of classical mechanics, its effectiveness remains extremely limited (it does not explain the behavior of the system with the n electrons or the DAVINSON and GEMM interference).

A coherent and more general theory needs to reconcile the double aspect of the electron which, according to the type of experience, appears either as a materialized corpuscle or as a wave with a definite frequency [67].

A reasoning by analogy between the behavior of the electromagnetic waves, which also are sometimes in the form of waves, in the proper sense, and the form of grains of light or photon led BROGLIE to discover a fundamental relation between the electron as a particle and its amount of movement and this same electron is characterized as a wave.

$$2\ \pi\, r = n\ \lambda = \frac{mh}{mv}$$

$$\lambda = \frac{h}{mv} \qquad (14)$$

See : theoretical representation in thermal physics [51] p. 51 and
- SCHRODINGER's non-relativistic equation

$$-\frac{h^2}{8\pi^2 m}\ \Delta\varnothing + U\varnothing = \frac{h}{2\pi}\frac{d\varnothing}{dr} \qquad (15)$$

compared with (8) the relation of terms
- equation determining the possible values of E
( $\chi_\alpha$ is the space variable)

$$\Psi(x\alpha t) = \varnothing\,(x\alpha)e^{-\frac{2i\Pi E^{t}}{h}} \qquad (16)$$

after reduction

PØ = E Ø (17)

function E = function P

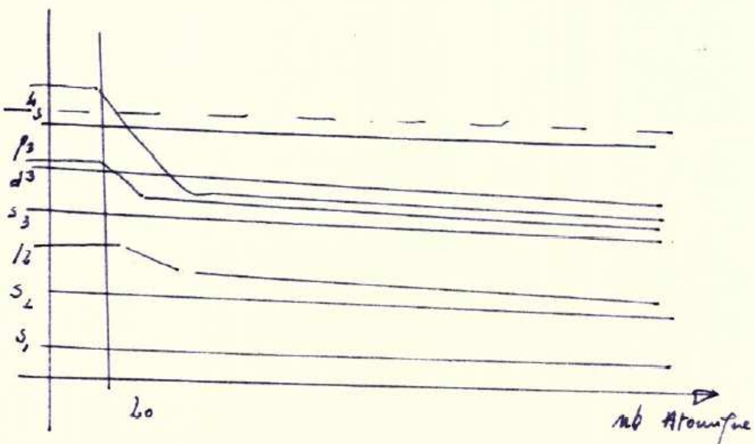
(energy) (operator) (51)

Used in optics (SCHRODINGER) and in mathematics (HEISENBERG and JORDAN) this led to the formulation of a certain number of postulates whose exploitation constitutes the undulatory mechanics :

POSTULATE 1 – A relation exists $\lambda = \frac{h}{mv}$ (14)

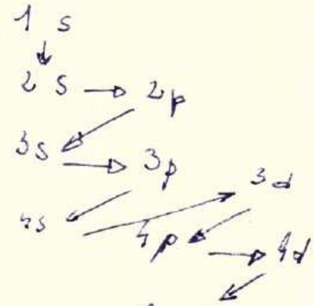
POSTULATE 2 – It is not possible to determine simultaneously with precision the position of a particle and the amount of its movements.
The probability of presence is :

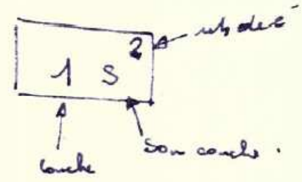
$$\psi\ \psi^*\,dT = I\ \psi\,\mathrm{I}^2 dT \qquad (15)$$

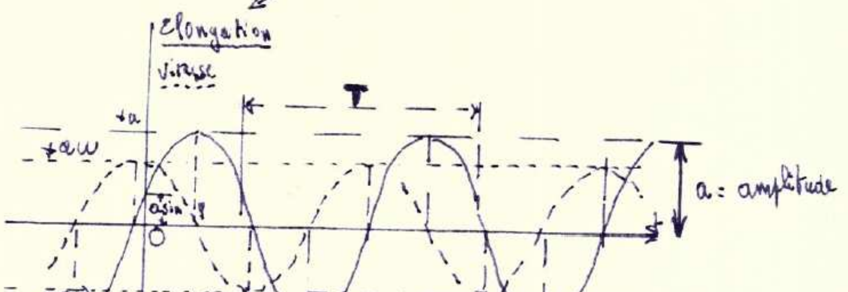



graphique montrant le chevauchement orbitale en fonction de la charge du N

(dessin 43)

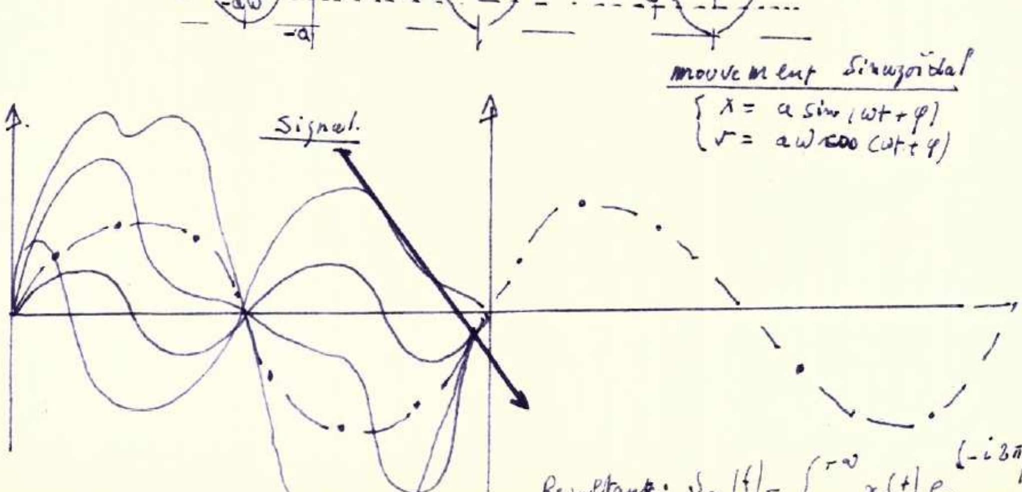



mouvement sinusoïdal

$$\begin{cases} x = a \sin(\omega t + \varphi) \\ v = a\omega \cos(\omega t + \varphi) \end{cases}$$




Resultante: $S_x(f) = \int_{-\infty}^{+\infty} x(t)\, e^{(-i2\pi f t)}\, dt$

POSTULATE 3 – In a movement of one dimension, the result of the imprecision on the abscissa by the imprecision on the measurement of the amount of movement is constant and around the size of $\hbar$

Thus : $\frac{h}{2\pi}$ Δx Δpx $\cong \hbar$ (16)

This is HEISENBERG's principle of uncertainty which is applicable to all movement or form Ml² $T^{-1}$

From this we can possibly know the energy and its time.

W = F Δx

donne (mj) donne $\frac{v}{t}$ et donne $\frac{\Delta x}{r} \rightarrow \gamma = \frac{\Delta x}{t^2}$

W = $\frac{m\Delta x^2}{t^2}$ (= ML² $T^{-2}$) (17)

The energy of a system (isolated and perhaps stuck on the notion of uncertainty energy) [53].

<u>II – 3 – 4 - 2 – Principle of uncertainty</u> [53 - 51]

(Drawings 25 b and 26).

The total mechanical system of an isolated quantum system is not strictly constant. If the system only exists during an interval of time $\Delta t$, its energy can be defined best by :

(18)

$$\Delta E \ \ \Delta t \ \cong \ \hbar$$

Again this concerns a relation of uncertainty but it is tied to the definition of the energy in the usual time. The time of the system is sufficiently negligible so that we can disregard this.

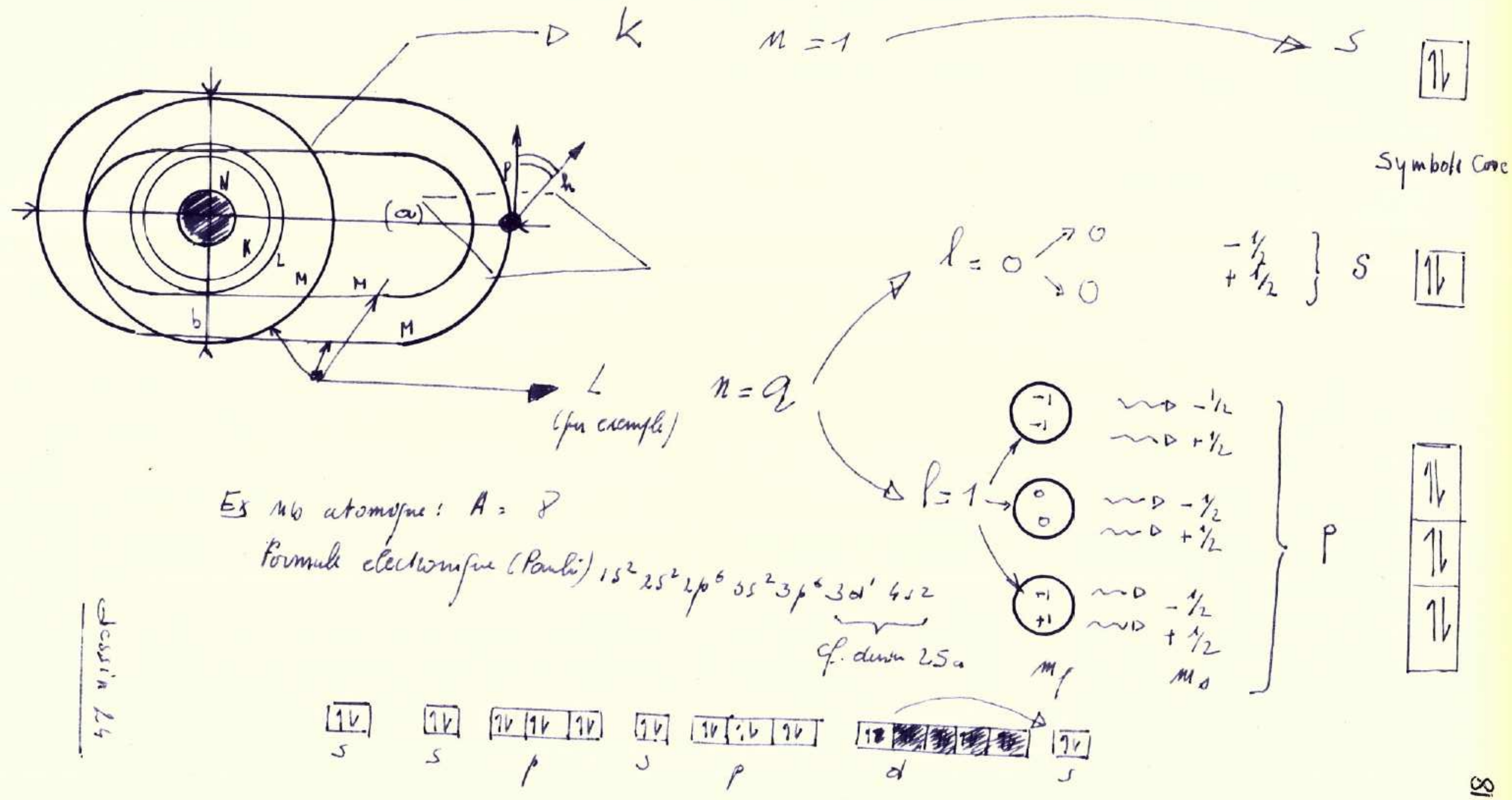
The certainty to encounter an atom in a precise orbit is absolute, but in undulatory mechanics there is only an elementary possibility dP.

The probability precision will be better defined by knowing the wave's function.

$\psi$(xy3) (19)

With regard to the probability, this function plays the same role as that played by the electrical field $\bar{e}$ in relation to a light's wave intensity, thus

$$\psi_2 = P$$


K
n = 1
s
Symbole case
(a)
b
N
K
L
M
l = 0
- 1/2
+ 1/2
s
n = 2
L
(par exemple)
l = 1
p
m l
m s
Ex no atomique : A = 8
Formule électronique (Pauli) 1s2 2s2 2p6 3s2 3p6 3d1 4s2
cf. dessin 25a
s
s
p
s
p
d
s
dessin 24
81

(where P is always the probability of presence)

Later on we will use (19) constantly.

In an isolated mono-atomic system, this function corresponds to the conditions for which the value of the total energy T is defined. This function is a solution of the SCHRODINGER equation which we can now write as :

$$\frac{\hbar}{2m}\Delta\psi + [W - v\psi(2y3)] = 0$$

$\psi$ = energy of the system's own functions

$m$ = laplacian's

$$\Delta\psi = \frac{\theta^2\psi}{dx^2} + \frac{\theta^2\psi}{dy^2} + \frac{\theta^2\psi}{d3^2}$$

$v$ = speed of the particle

The $\psi$ solutions functions are functions belonging to the system, and the T functions are the values belonging to the energy.

Conclusion :

At any moment the position (x, y, z) and the speed of one $\bar{e}$ cannot be defined in a precise manner. We can only define the whole.

### II – 3 – 5 - Spectrum and radiation : its energy [68 - 74]

#### II – 3 – 5 – 1 –

If we study the interactions between radiation and matter (the Raie spectrums for example), we see that the radiation occurs in quantified leaps.

The wave and photon concepts cannot be dissociated even though they are opposite like the back and front of a sheet of paper.

The purpose of this exposé is not to delve into atomic physics. We will simply give some examples of the interactions which lead to energy levels that we will soon put to use.

Let us first consider the nucleus of the atom of charge Ze and an electron of charge e and of mass m. The quantification of the movement shows that the energy of this system can only take values :

$$W_n = \frac{-z^2 e^4 m}{\gamma \varepsilon_0^2 h^2} \quad \frac{1}{n^2} \qquad (22)$$

So n = whole number (of orbits)
$\varepsilon_0$ = basic electromagnetic coefficient

When there is a variation of one unit, the emission is approximately one electronvolt.

The electron's energy is indeed found in this form (kinetic energy and potential energy due to the movement and mass of the electron) but there are also other forms of potential energy due to [68].

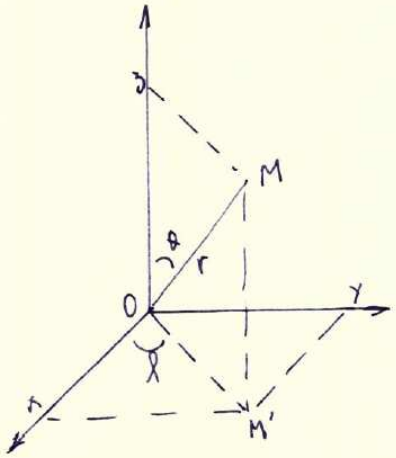
- Electrical forces :
The various signs attract each other and the same signs push each other. This is the case with the nucleus and the electron.

- Magnetic force :
This is due to the magnetic poles which also involve the forces of attraction and repulsion.

These same electrons possess : the energy of rotation
(by turning around themselves, the electrical and magnetic forces produce energetic interactions).
the energy of vibration
(the electrons are in vibration)

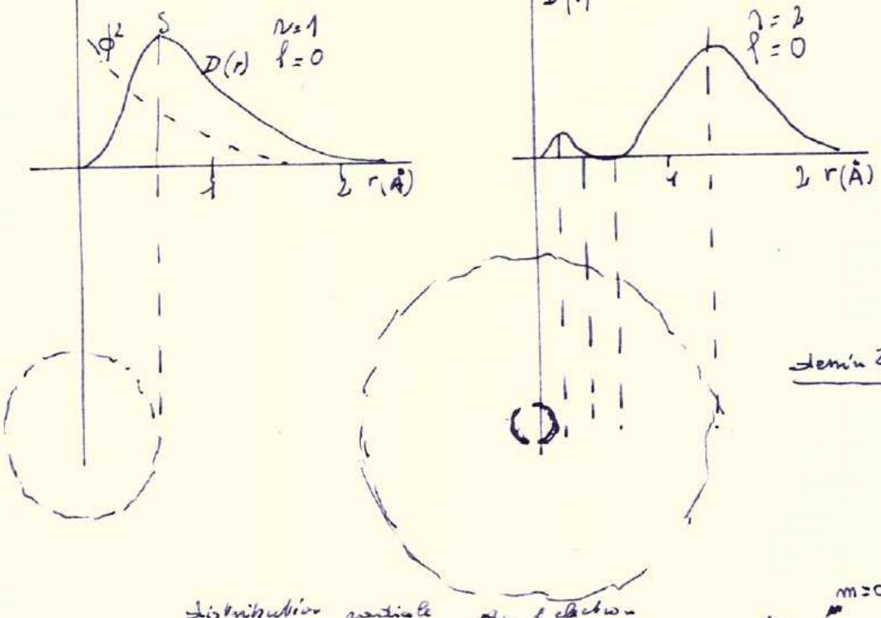
We now understand the interest of knowing the exact structure of the atom and we see the energetic importance represented by the two last vibratory and quantum numbers $m_l$ and $m_s$.

Knowing that the build-up of the atom obeys two principles attributable to PAULI [71], we have :




(dessin 25 a)

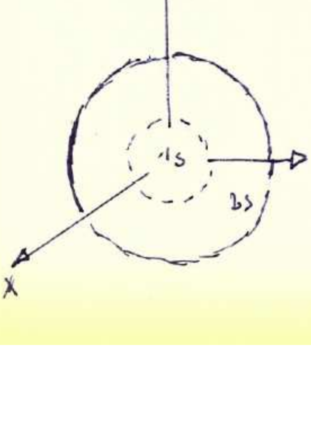
coordonnées polaires et cartésiennes

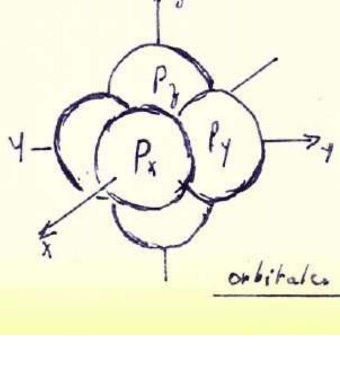


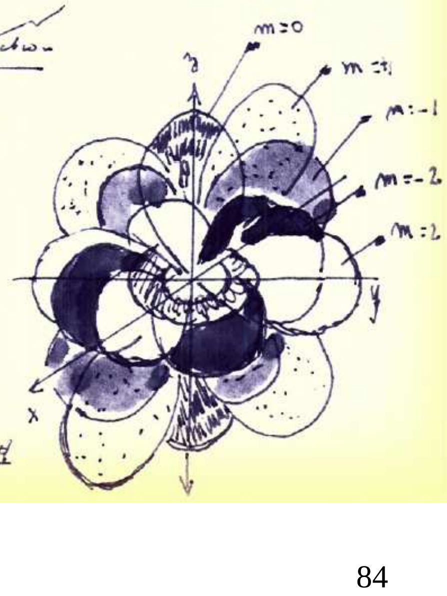

dessin 25 b

distribution radiale de l'électron

(dessin 26)




orbitales s.p.d

The principle of exclusion :

In the same atom, there cannot be two electrons with the same 4 quantum numbers.

The principle of stability :

During the build up of atoms involving a growing number of electrons, the electrons arrange themselves by occupying the successive levels of energy at the lower levels (drawing 24).

By these two principles of exclusion and stability, we can determine an atom's electronic configuration in a very precise way. In the same manner we can deduce the energy variations related to the large or small structural changes, energetically speaking.

## II – 3 – 6 – Examples of levels of energy

If we study the spectrum lines closely, we find that they have a multiplex structure (they are divided into several zones). If the transition from one layer to another represents a few electronvolts that are perfectly visible in the yellow light of the sodium, there are also much weaker energetic separations : hertzian spectroscopy (see drawing 27 a and b).

$$\Delta W = \frac{hc}{\lambda^2}\ \Delta\lambda \cong 2{,}5\ \ 10^{-3}\ \mathrm{cv}$$

It is necessary to look for these variations in what the quantified orientation represents of a moment in a magnetic field. Each electron is like a little magnet with a magnetic moment. It gives birth to very diverse and closely-related levels of energy.

$$\text{If } \hbar \cong \frac{h}{2\pi}$$

The projection of a magnetic moment M called $M_z$ (which is colinear to the kinetic moment M) in the direction of field B sets the magnet's energy (drawing 28 a).

$$W = -\mu\ \mathrm{B}\cos\ \theta = -\mu z\mathrm{B}$$

This leads us to explain that :

1°/ - The proposed kinetic moment of the electron is $\frac{1}{2}$ or $\frac{-1}{2}$ (confronted before) which in projection takes the values : $\frac{+1\hbar}{2}$ and $\frac{-1\hbar}{2}$ and the magnetic moment proportional to the kinetic moment equals :

$$Mc = 2{,}00232 \ \frac{e}{2m} M$$

The small magnet is placed in the magnetic field created by the circular current, the same as an electron turning around the nucleus. When the atom is in its fundamental state, this easy-to calculate field is :

$$B = \frac{1}{4\pi\varepsilon_0 c^2} \frac{e\hbar}{2m} \frac{1}{r_O^3}$$

ro = BOHR's line. Two orientations of SPIN in the magnetic fields are possible (see drawing). The gap of energy is :

$$\Delta E = \mu e B_0 \,.\, (-Me\, B_0)$$
$$= 2\ Me\ B_0$$

i.e. a few milli-electronvolts.

2°/ - In the same way, a spin of the electron orients itself in the field created by the nucleus and : $\Delta E \cong 10^{-6}$ ev

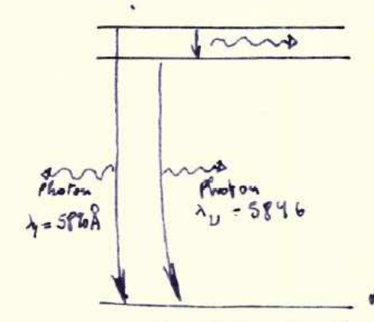
$\Delta$nt 1430 Mhz for $H_2$ (drawing 28 b)

All this means is that we have diverse levels of energy, but also in the formula :

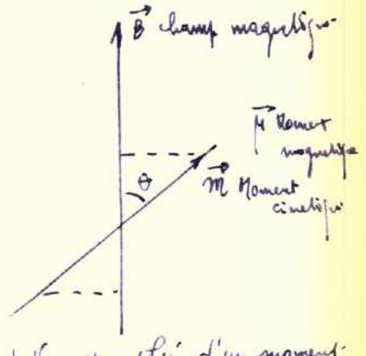
$$W = -\mu B \cos \theta$$

by orienting the magnetic moments of certain atoms in an exterior magnetic field, even from the outside we can make the various energy levels appear (drawing 28 c).

It should be noted that this only occurs in the hertzian spectrum because the nature of the size of the achievable magnetic fields and of the atomic moments lead to levels whose spacing is approximately that of the milli-electronvolt (valid for the maser but not for the laser).



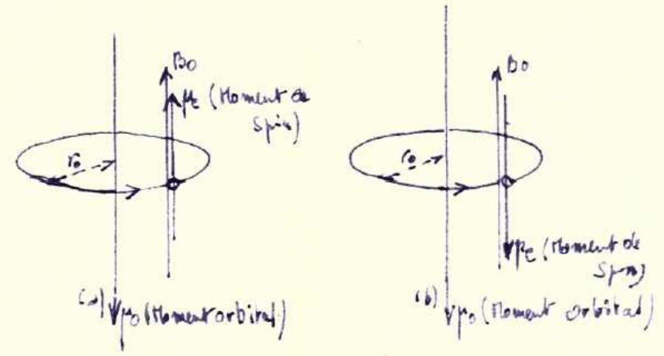

démultiplication d'un niveau et la structure fine des raies



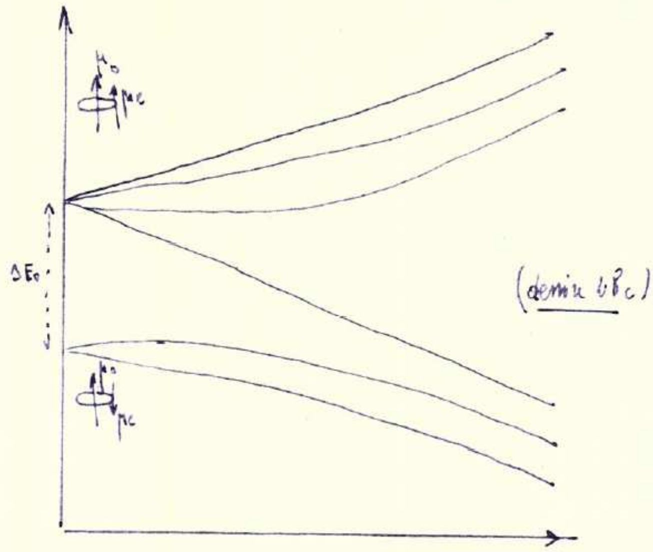

orientation quantifiée d'un moment dans un champ magnétique

(dessin 28a)

(dessin 27)




(dessin 28b)




Niveaux démultipliés obtenus par l'action d'un champ magnétique extérieur sur le moment résultant d'un atome

**<u>II – 4 – LIGHT WAVE</u>** [68]

<u>II – 4 – 1 – Relation between the duration and the width of the band</u>

In a spectrograph none of the photons emitted during the transition have the same energy.
The spectral line is not a point but a stain of a certain width. To completely describe this phenomenum, we must introduce a "distribution" (the emitted photon has an energy included between hv and h(V+dv) ). The probability is :

$$\int_{-\alpha}^{+\alpha} \rho\,(v)\ dv = 1$$

Where the value p(V) is very weak but very close to the frequency $V_0$ in other words a closeness of the "proper frequency" of the transition.
Often , the form of the ray is very well described by a relation of the form :

$$\rho\,(V) = \frac{2}{\pi\Delta v} - \frac{1}{1+4(\frac{V-V_0}{\Delta V})^2}$$

Where $\Delta V$ is the width of the ray.

As long as the frequency is included in an interval $\Delta V$ around $V_0$, the probability is higher than half the maximum. If one considers the case of the photons emitted by the molecules of a hot gas (great thermal agitation speed) the results are given by :

$$\rho(V) = \frac{2\sqrt{Log^2}}{\sqrt{\pi\Delta V}} \qquad \text{(gaussian distribution)}$$

Where $\Delta V$ is always the "width of the ray".

This enlargement of the spectral rays has a a great consequence. If we consider the light beam emitted by a source, we have represented it until now by a sinusoidal vibration of the form :

$$\psi_0 \sin 2\pi V_0 t \qquad \text{(Schrödinger)}$$

The life being infinite : t : - $\alpha$ t = +$\alpha$ and, the frequency $V_0$ was precisely determined. But this is not the case. The mathematical description (FOURIER's integral) of the light beam results in the superposition of waves from neighbouring frequencies, all spread out on a band of width $\Delta V$ which is centered on $V_0$.

The emitted wave is approximately described by a sinusoidal whose most probable frequency is equal to $V_0$ and the limited duration. The life $\Delta$t is tied to the width of the band which gives the following relation :

$$\Delta V . \Delta t \cong 1$$

Thus the wider the ray, the shorter the length of the string of waves emitted by the light source. If we measure the light vibration phase at two different moments t1 and t2 (t1 is inferior to t2), we must consider two cases :

-the gap between the twomoments is inferior to the life. We will have :

$$\varphi(t_2) - \varphi(t_1) = 2\pi V_0(t_2 - t_1)$$

and we will remain in the same string of waves. The difference in the phases between t1 and t2 is very clearly defined : the beam possesses the temporal coherence.

- On the other hand, if the interval t1 and t2 increases and becomes superior to the life $\Delta r$ , the strings of waves will be different and the difference in the phases between the two instances is no longer defined.

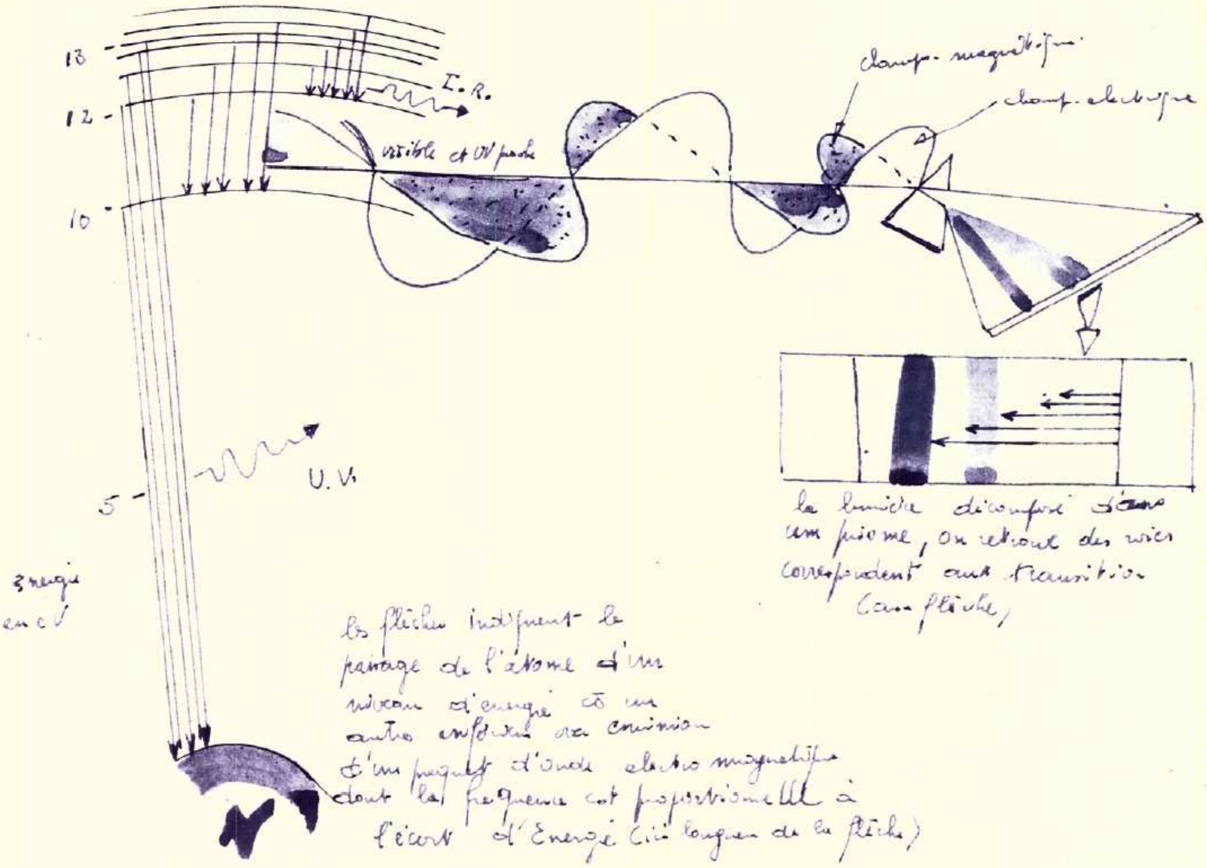
We can retake the numerous measurements at different instances and do the average of the differences of the phases obtained.

The result will be :

$$[\ \varphi\ (t_2) - \varphi\ (t_1)] = 0$$

We say that the beam is temporally incoherent.

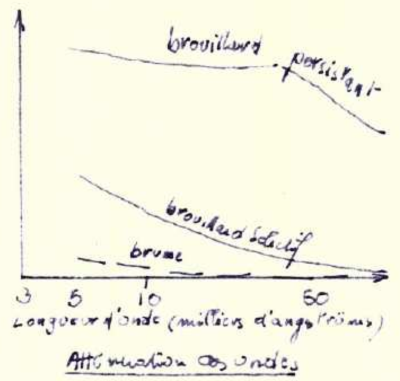
We can compare this phenomenum to the spatial coherence even though the origin is different. For a source to be "spatially coherent", all the elements must vibrate in the phase. This is impossible with the usual sources but possible with lasers.




la lumière décomposée dans un prisme, on retrouve des raies correspondant aux transitions (aux flèches)

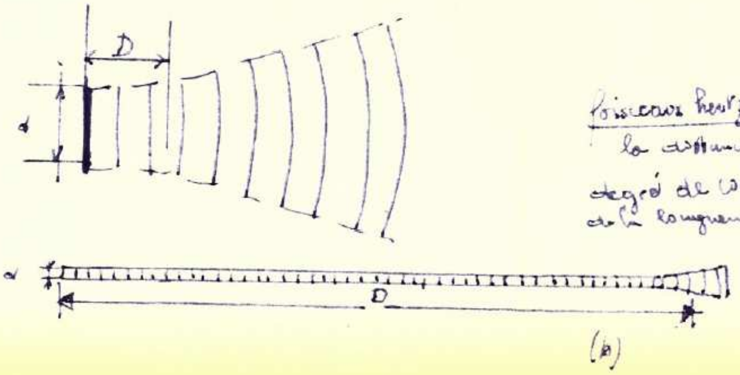
les flèches indiquent le passage de l'atome d'un niveau d'énergie à un autre inférieur avec émission d'un paquet d'onde électromagnétique dont la fréquence est proportionnelle à l'écart d'énergie (ici longueur de la flèche)

(dessin 69a)




Atténuation des ondes

(dessin 69b)




(b)

Faisceaux hertzien et laser (b)

la distance D et le degré de conicité ultérieur dépendent de la longueur d'onde et du ø de la source

The emitted vibrations can interfere at the same instant with different points of the source. To create a temporally coherent source, it must be as "monochromatic" as possible. Two vibrations, emitted by the same element of the source at two different instances will only interfere if the time interval is lower than $\Delta t \cong 1/\Delta v$

The lasers supply the solution, they allow us to diminish the width of the rays.

II – 4 – 1 – 1 – Principle of the measurement of the temporal coherence

(see drawing 30)

Let us cause a transmitted vibration to interfere directly with a vibration which is reflected twice. Let us examine the aspect of the interferences when we increase the distance between the mirrors. If the interference rings disappear, it is because the distance is too great. Therefore, the vibrations which should interfere belong to two different strings of waves.

II – 4 – 1 – 2 – Causes of the widening of a spectral ray

The most important of these is the one due to the DOPPLER effect. The light source is animated at a speed (v) in relation to the receptor. The frequency perceived by the observer is slightly different from the frequency emitted. The spread of the frequency is :

$$\frac{\Delta v}{v} = \frac{v}{c}$$

In a gas where there is an electrical discharge, the light emission (gas at 100°K), the speed of the thermal agitation is approximately 700m/s (if the gas has the same specific mass as the air). Therefore, in the visible spectrum the widening will be around $2.10^{-6}$ or in wavelength for = 6000 Å $\Delta\lambda$ = $12.10^{-3}$ Å. This is important but not a problem for the laser considering its properties.

If we enclose the atom emitter in a crystalline network, the DOPLER effect no longer plays the principal role. In this case, the widening is due to the interaction of the atom's electrons with the group of charges which are in the body.

The infinitely thin levels of energy are the result of the interaction of an electron with a nucleus. In fact, it is more complicated, it involves an interaction of all the electrons and all the nuclei. The levels become reduced but are so close and numerous it is as if the infinitely narrow level is replaced by a band of energy. This is also what is produced in the magnetic reactions where the spins play on each other.

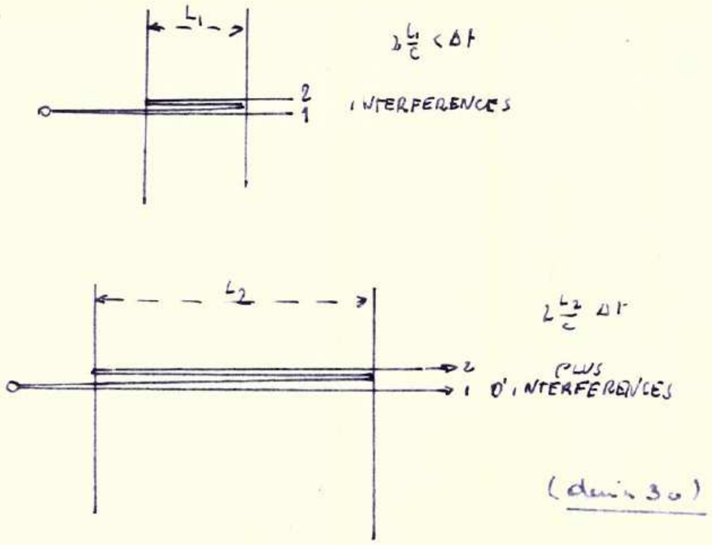
Therefore to achieve a temporal coherent source, we do not have to use solid bodies, or liquids, or even gas. In solids and liquids, the emitters are disturbed by the environment. In gases, as we have just seen, the DOPPLER effect has no favourable effect (see the variation in amplitude during the trajectory of the wave).

All that remains for us is the solution of the isolated atom. The light emission is weak but the temporal coherence is perfect. In fact, it is not entirely satisfactory to consider the isolated atom as a temporally coherent source. It only emits light after being stimulated when it passes from its excited level to its fundamental level when it ceases to emit.

Thus the duration of the string of emitted waves is determined and the spectral ray is enlarged. This is very weak in relation to the phenomena described above because the "natural" width of the rays of the isolated atom is $6.10^{-5}$ Å.
In conclusion, the life and the width of the band are inversely proportional. All environments increase the length of the band and consequently diminish the life resulting in temporal coherence.

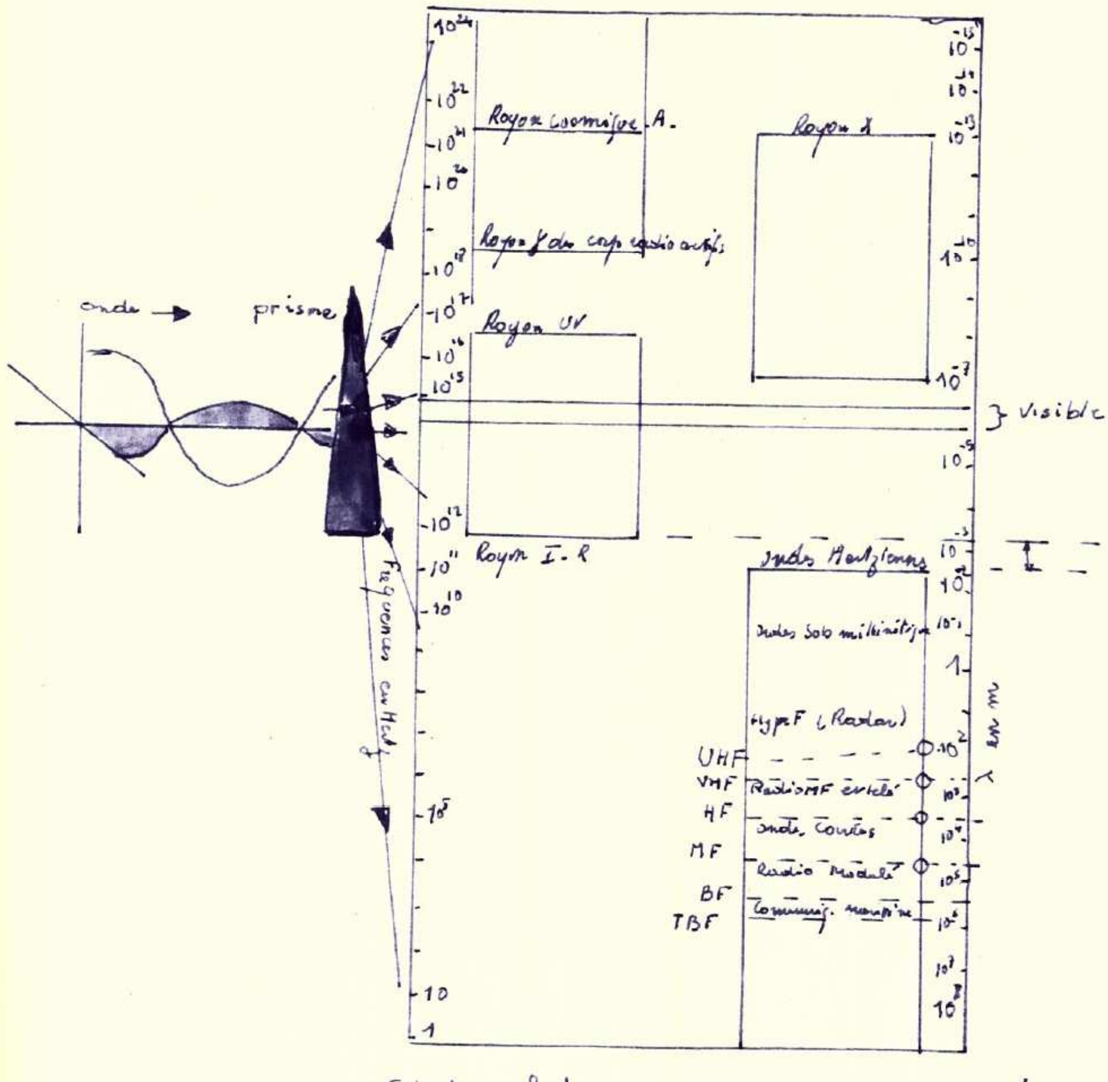
II – 4 – 2 – What must we conclude from the observation of a succession of waves ?

Generally a detector receives only an average of the effects produced by the source of the values of a (t). (We consider the precision detector enormous before T'). An atom emits a complex vibration $\nu_1 t$, $\nu_2 t$ …at time $t_{1'}, t_2$ ….distributed around.




largeur de raie
(interféromètre Perot Fabry)

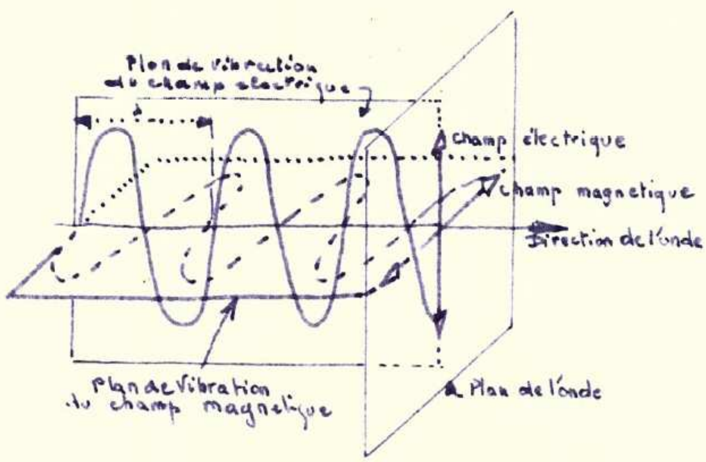
(dessin 30)

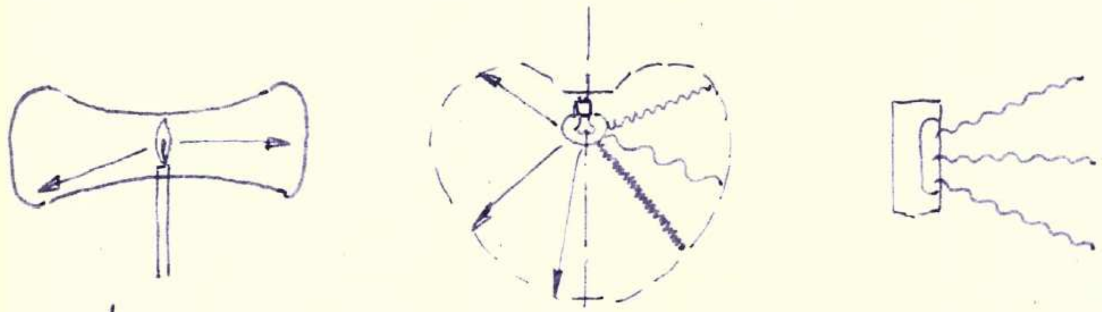



Spectre électro magnétique

(dessin 32)

# Onde.



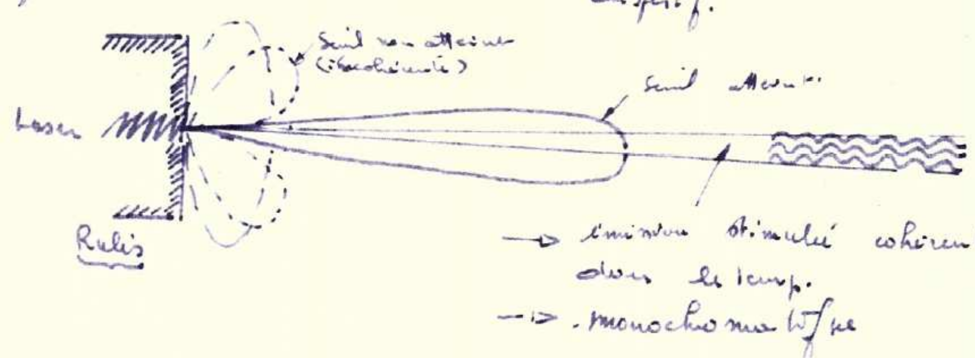
bougie

lampe.

Vapeur Hg.

longueur d'onde (λ) différente
→ polychromatisme
émission de hasard
→ incohérence.
très dispersif.

une seule longueur d'onde
→ monochromatique.
pas de coïncidence de phase
→ incohérence.
dispersif.




→ émission stimulée cohérente dans le temps.
→ monochromatique

dessin 81

The expression $v_1t$ , $v_2t$ is an analytical signal associated with the real vibration. The emitted vibration at time $t_1$ is represented by : $v_1(t-t_1)$ at time t. Thus this way for other atoms and complex vibrations lead us to consider that at time t, the vibrations which leave the atom are :

$$V(t) = v_1(t-t_1) + v_2(t - t_2)$$

The phase of each wave is variable and there is no relation between any of the waves.

For each wave we have :

$$v(V) = v_1(V)\, e^{-J2\pi V t_1} + V_2(V) e^{-J2\pi +^2}$$

Where :

$$v(t) = 2 \int_0^{\alpha} [v_1(V) \; {}^{-J2\pi v t_1}_{+\ldots+\ldots}] \; e^{J2\pi v t dv}$$

Thus :

$$V_1(t-t_1) = 2\int_0^{\alpha} v_1(V)\; e^{J2\pi V(t-t_1)}_{dv}$$

Therefore 3.1 and 2.2 are identical. The complex vibration translated by one or another of these expressions represents the succession of waves emitted by an atom.

Because all waves are incoherent, there is a slight difference between one emitting atom and another. The vibratory complex v (t) given by 2.2 or 3.1 can represent the emission at a time t of an extensive incoherent source. Besides, v(t) corresponds to a monochromatic vibration. Consequently, one can characterize the emission of an extensive incoherent source by the vibratory complex v (t). If the light is quasi monochromatic, we use the expression :

$$a(t) = a(t)\, e^{-J\o}\, t$$

and

$$V(t) = a(t)\; e^{J2\pi V o t}$$

A detector (a photoelectric eye or cell, for example) is sensitive only to the value $v^2$ t.
The intensity of the phenomenum is naturally characterized by the form :

where T is the time needed to obtain the observation. Now T is also very wide in relation to the temporal coherence. One can write :

$$v^{'r)^2(t)} = \lim_{T\to\alpha} \frac{1}{2\pi} \int_{-T}^{+T} v^{(r)^2}(t)\,dt \qquad \textbf{(1)}$$

but if the integral (1) is limited, T to the infinite, the integral (2) is divergent.

$$\overline{v^{(r)^2}(t)} \cong \frac{1}{2T} \int_{-\alpha}^{+\alpha} v^{(r)^2}(t)\,dt$$

The difficulty disappears if one considers its overall function v$\frac{r}{T}$ (t) equivalent to the function $v^{r}$(t) in the interval –T, T is identical to zero outside of this interval. In this line of thought, we keep the notation $v^{(r)}(t)$

One can write :

$$\overline{v^{(r)^2}(t)} = \frac{1}{2}\,\overline{v(t)\,v^{*}(r)}$$

$$= \overline{v^{(i)^2}(t)}$$

In the current state, the operations in time are linear. One can make calculations with v (t) and take the real part of the final calculation. The relation is important because <u>it shows us that one can find the value of the square of the real vibration (of the light intensity) using the wave that is associated to it.</u>

## <u>II – 4 – 3 – Coherence of the vibration</u>

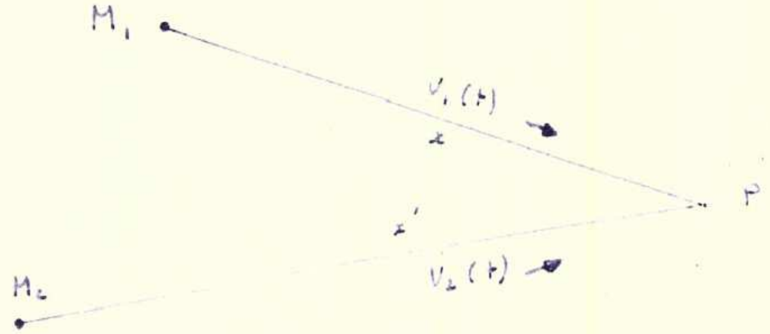
In previous studies we explained what coherence is. Now according to this coherence, we will determine the intensity that any point P receives which emanates from distinct sources. If we consider the vibratory complex $v_1$t and $v_2$t emitted by two sources $m_1$ and $m_2$ (see drawing 33), the vibrations are superposed to point P.

For the moment we do not specify the nature of these two sources. It is possible that the vibration emitted by these two sources be the image of the same source. In opposition these two sources can be completely independent as we have already seen. We consider them as two different sources.

calcul de I

"mutual coherence"

**dessin 33**




temps $\theta_1 = \frac{M_1 P}{v}$

$\theta_2 = \frac{M_2 P}{v}$

(I)

en $M_1$ $V_1(t) = 2\int_0^{\infty} v(M_1, \nu)\, e^{j 2\pi \nu t}\, d\nu$

en $P$ $V_P(t) = 2\int_0^{\infty} v(M_1, \nu)\, g(\nu)\, e^{j 2\pi \nu (t - \theta_1)}\, d\nu$

(II)

complexe vibratoire au temps $t$ au point $P$

$$V_t = V_1(t - \theta_1) + V_2(t - \theta_2)$$

l'intensité observable en $P$ est

$$I = \overline{V(t) V^*(t)} = 2\,\overline{V^{(r)2}(t)}$$

donc

$$I = \overline{[V_1(t-\theta_1) + V_2(t-\theta_2)][V_1^*(t-\theta_1) + V_2^*(t-\theta_2)]}$$

l'intensité de l'onde est considérée stable

$$\overline{V_1(t-\theta_2)\, V_1^*(t-\theta_1)} = \overline{V_1(t)\, V_1^*(t)} \quad \text{idem pour } \overline{V_2}$$

$$\overline{V_1(t-\theta_2\;\; V_2^*(t-\theta_2)} = \overline{V_1(t+\theta)\, V_2^*(t)}$$

donc :

$$V_1(t+\theta) V_2^*(t) + V_1^*(t+\theta) V_2(t) = 2\,\mathcal{R}[V_1(t+\theta) V_2^*(t)]$$

$$I = \overline{V_1 V_1^*} + \overline{V_2 V_2^*} + 2\,\mathcal{R}[\overline{V_1(t+\theta) V_2^*(t)}]$$

donc $I = I_1 + I_2 + \underbrace{2\,\mathcal{R}[\overline{V_1(t+\theta) V_2^*(t)}]}$

$\Gamma_{12}\,\theta$ (cohérence mutuelle)

Variation des Amplitudes durant la trajectoire de l'onde. 98

(dessin 34)

① La fonction du temps pour une vibration sinusoïdale peut être écrite

$$E = a \cos \left[ 2\pi \nu \left( t - \frac{x}{v} \right) + \theta \right] \qquad (1.1)$$

pour une onde sphérique dont le centre est $x$

$$E = \frac{a}{x} \cos \left| 2\pi \nu \left( t - \frac{x}{v} \right) + \theta \right| \qquad (1.2)$$

où : $a$ = amplitude.
$\theta$ = phase
$\nu$ = fréquence $= \frac{\omega}{2\pi} = \frac{1}{T}$
$x$ = point considéré central
$\omega$ = fréquence angulaire.
$T$ = période
$\lambda$ = longueur d'onde. (wavelength of vibration)

② En vérité un rayonnement n'est pas infini énergétiquement parlant, il y a une décharge progressive de l'onde

Si une représentation réelle de l'onde monochromatique est

$$V^{r}(t) = \int_0^{+\infty} b(\nu) \cos \left| 2\pi \nu t - \Phi(\nu) \right| d\nu \qquad (2.1)$$

où $b(\nu)$ amplitude réelle
$\Phi(\nu)$ phase réelle

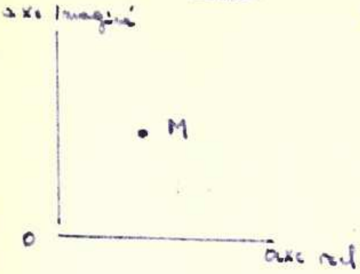
nous utiliserons désormais

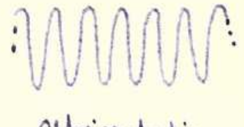
$$V(t) = 2 \int_0^{+\infty} v(\nu)\, e^{-2\pi \nu t}\, d\nu \qquad (2.2)$$

③ Si $\nu_0$ est la fréquence de départ (1-1) nous donne

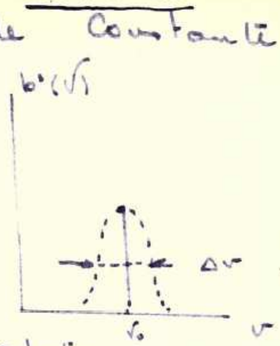
$$V(t) = \exp j \left| 2\pi \nu_0 \left( t - \frac{x}{v} \right) + \theta \right.$$

1er cas – nous considérons l'amplitude constante dans le temps



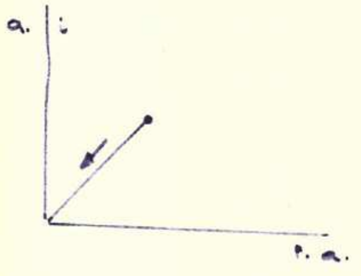



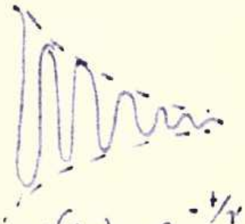
représentation réel de $V^r(t)$




• spectre —
• spectre atomique réel ....)

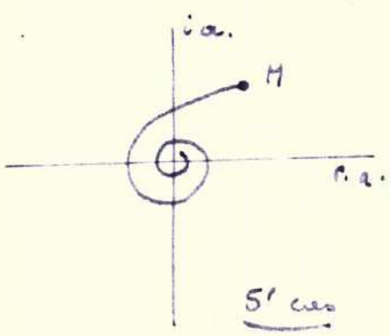
2e cas – l'émission d'un atome n'est pas éternelle
(voir avant) elle dépend de τ (temps de cohérence.



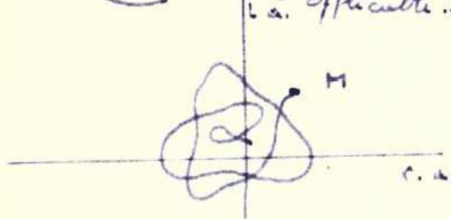



$$V(t) = e^{-t/\tau} e^{j(2\pi\nu_0 t + \theta)} \qquad (3.2)$$

3e cas. – effet Doppler

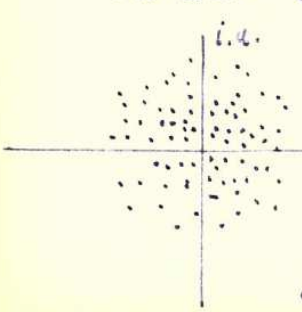


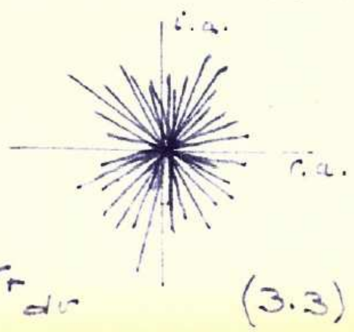

4e cas. cas général toujours i.a. applicable....




5e cas Succession d'onde par un atome.

pour le temps nécessaire à l'observation T est très petit ;
a(t) représente un grand nombre de valeurs réparties autour
(un grand nombre de sinusoïdales)
On reçoit en général seulement la résultante des a(t)




donc : $$V(t) = 2\int_0^\infty v(\nu) e^{j2\pi\nu t} d\nu \qquad (3.3)$$

The calculations explained on the following page give us the vibration at point P, at time t. In these calculations, we considered that when the vibration ($v_1$) emitted by $m_1$ arrives at P, it has covered a distance $m_1$P.
We consider the index of refraction equal to 1. If $i_1$ and $i_2$ are the respective intensities of $m_1$ and $m_2$, the intensities in $P_1$ of the two sources are independent.

In this study we consider these two values as constant. On the other hand, x and x' have a fundamental role as all variations would have important consequences. To simplify the calculations, we take the vibration in P at time T, the same as that in $m_1$.

In these conditions, we can write the intensity at point P in function of that issued by $m_1$ and $m_2$ (see diagram). From this we deduce the value of the mutual coherence. We understand that with these data we can calculate the intensity i at point P superposed by the two vibrations $v_1$ and $v_2$

### II – 4 – 4 – Photometry [58 – 83 – 84 - 85]

Photometry is the basis of our measurements and is itself the measurement of light intensities.

Two sources producing the same illumination at an equal distance have equal light intensities.

#### II – 4 – 4 – 1 – Measurements

Light intensity

We have a light source S. We consider the solid angle cone to be very small $\Delta W$ and on axis Sx. The luminous flow $\Delta ø$ will be defined by :

$$\Delta ø = I \quad \Delta W$$

where I is the light intensity in direction Sx.

In other words, I is none other than the luminous flow emitted by the solid angle unit
$\Delta$ W = 1 in direction Sx.

Lighting

The lighting is the luminous flow received by a screen's surface unit.

$$E = \frac{\Delta ø}{\Delta S} = I \frac{\Delta W}{\Delta S}$$

The average lighting E is the quotient of the flow $\Delta ø$ per surface $\Delta S$ of a small lit screen . The lighting in a point is the limit towards which the quotient $\Delta ø / \Delta S$ tends when $\Delta S$ tends towards zero.

Unit of intensity

International candlepower (sun : 3 $10^{27}$b)

In watt 1 erg : second (with a colorimeter : I= $\frac{W_0 \downarrow}{t}$

Unit of lighting

A unit of light is the lux or candlepower meter (light from a candle at 1 m).
It is not the same everywhere (see diagram).

Unit of flow

The unit of flow is the lumen.
The flow on 1 m² in a sphere of ray 1 m and of source 1 candle.

Intrinsic state of brilliance

This is the intensity emitted by a source per cm² of this source (candle/cm²).

**II – 5 - POSSIBLE ORIGINS OF A WAVE**

We have explained what are the principles which react on any electromagnetic wave i.

In our system we considered a simpler scanning and reflection procedure with recording using a photoelectric cell. This seems aberrant when one discovers the wonderful possibilities offered us by the laser.

To approach this laser we will first explain how a wave is emitted (its emission procedures) and from this proceed to the inference of what a maser is.

II – 5 – 1 – Origin of the emission [74]

If a gas is in a box, a thermal agitation makes the atoms rebound on the edges like golf balls. This leads, during encounters, to the evolution of the atoms at higher levels of energy. Upon the return of the initial energy $E_1$, a photon is emitted which forms the wave. This photon can do this same phenomenum itself.

Basing his studies on the knowledge of the time to which he added his own ideas, EINSTEIN argued that there are three ways an atom reacts with a photon.

- If an un-stimulated atom is hit by a photon having an energy equal to an interval in the scale of atom's energy, the photon is probably absorbed by the orbital system of the atom (drawing 37 a).

- If nothing else happens to the atom, sooner or later it will emit this stored up energy (drawing 37 b).

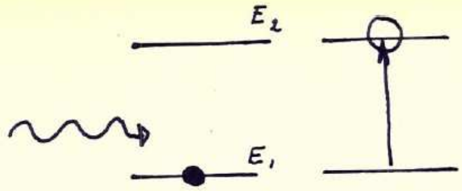
- If a photon hits a charged (photon in stock) atom (electron) it will stimulate the atom which will emit the stored photon. The energies become equal (drawing 37 c).

Let us look at this more closely.

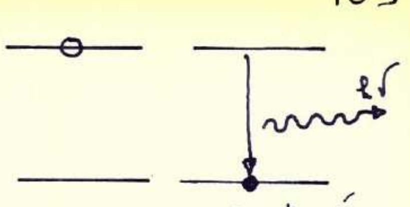
II – 5 – 2 – Stimulated and spontaneous emission [68 – 74 – 77 – 78]

We base our arguments on the previously studied "anatomy".
The stimulated emission, basis of the laser, (cf: ZEITSCHRIFT für Physik EINSTEIN 1918 volume 18).

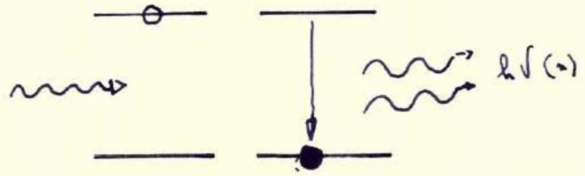
Let us consider the variations of energy $E_1$ and $E_2$ :



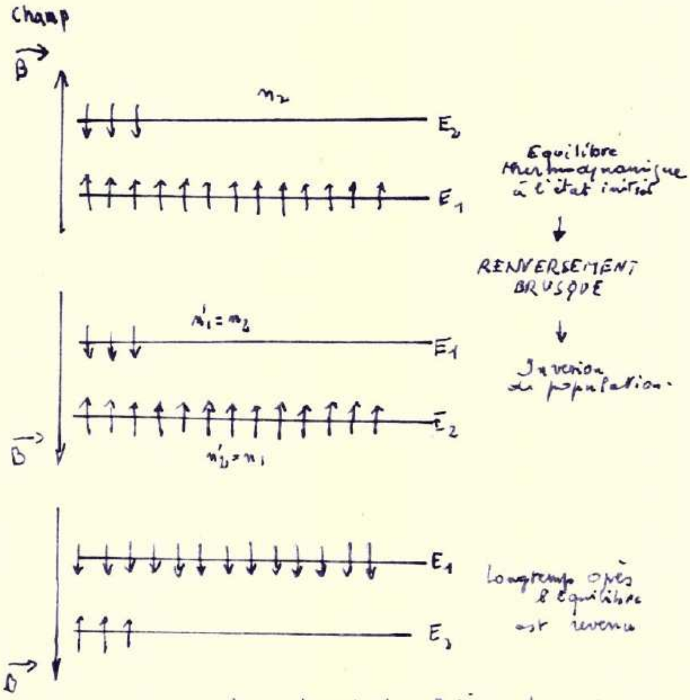

le rayonnement est absorbé si le e⁻ est sur couche inférieure.
(dessin 37a)




émission spontanée
(dessin 37b)

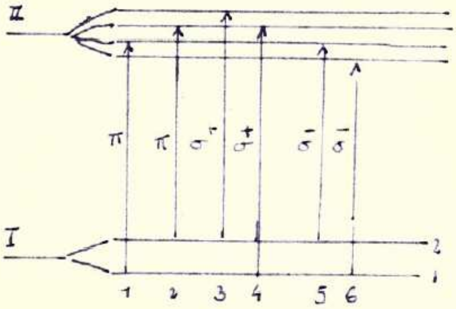



émission stimulée (dessin 37c) [6

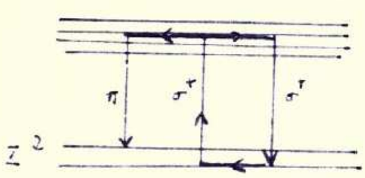



Inversion de population par retournement brusque de direction de champ Magnétique

(dessin 37 d) [68]




Principe du pompage optique
(dessin 37 e) [68]




(dessin 37 F) [68]

This is the result of photon emissions that have been diminished by the absorption of some of these photons.

---------

Where U is the variation of the density of the electromagnetic energy V, the emission is not satisfactory by this sole equation, the emission actually presents two aspects.

II – 5 – 3 - Spontaneous emission

There is a transition from level $E_2$ to $E_1$ by its own initiative without any exterior action.

II - 5- 4- Stimulated emission (EINSTEIN)

The emission increases with the number of photons contained in a cavity. A system $E_{2'}$ hit by a photon can go down to $E_{1'}$, therefore, to two photons. There is a progressive multiplication of photons and from this an amplification by stimulated emission of radiation.

This phenomenum is proportional : to the number of photons
to the population of level $E_2$

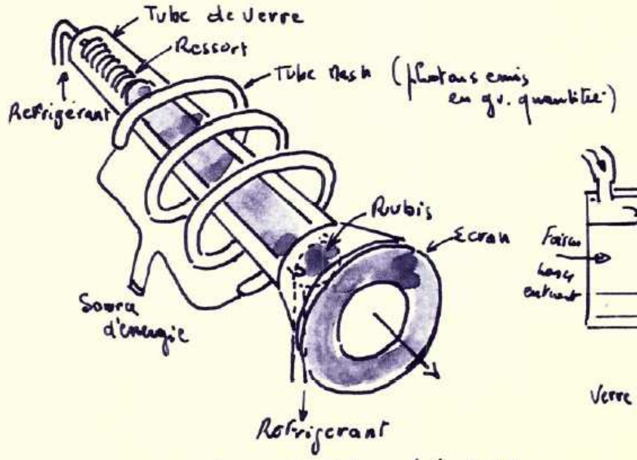
Thus at U $n_2$ there is no absorption.

Absorption and stimulated emission are equal (EINSTEIN's work). This is the photon side. Let us see what happens at the level of the wave :

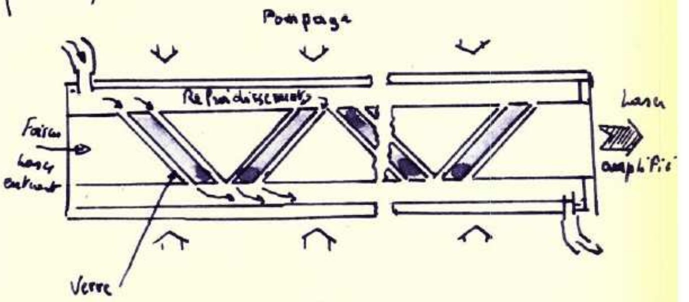
- the spontaneous wave with an aleatory spreading of 0 to 2 $\pi$ (tied to the goodwill of one of the systems which falls to the lower level).

- the stimulated wave is fundamentally different

The wave associated with the first ones commands the wave of the second one. The two waves are in phases therefore they have the same frequency but a superior amplitude therefore an amplification of associated waves.



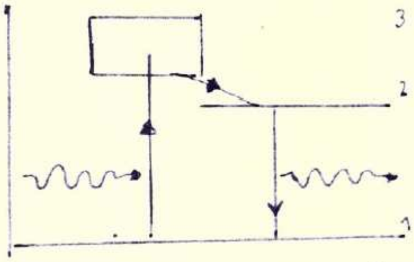

Laser à rubis pulsé [74]




Laser zigzag

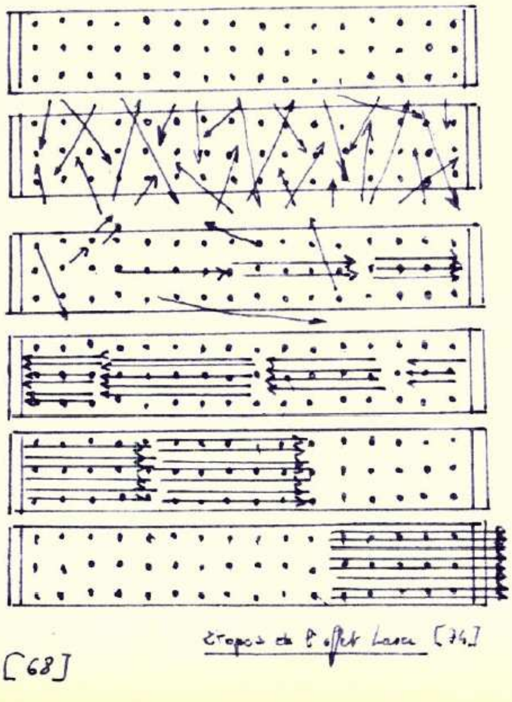
(dessin 40 b)

(dessin 40 a)




Laser à Rubis [77]

dessin 38 b



Etapes de l'effet Laser [74]

dessin 38c [68]

The variation of energy U per unit of time is $\frac{dU}{dt}$

If we bring energy (W) (radiation : by heating the walls or agitation).
Thus, $E_2$ increases to the detriment of $E_1$.
The cooling gives the opposite.

A system to which we supply the photons varies as does its population.
If U increases, $n_2 - n_1$ will reduce (asymptotic therefore never null).

Note : (cf : bibliography 74 and 71).

$$n_1 = \frac{k21 + A + BV}{k21 + k12 + A + 2Bv} N$$

$$n_2 = \frac{k12 + Bv}{k21 + B_{12} + A + 2Bv} N$$

One can therefore calculate $n_1 - n_2$

In nature, an atom is more in the fundamental state than in the stimulated state. Obviously there are passages from one state to another for certain parts of the atom : some absorb energy and others release it but the relative energy remains on the whole the same.

II – 5 – 5 – Population inversion :

This stimulated emission is very reduced in relation to the spontaneous emission. The population inversion's goal is to reverse in some way this normal and stable state of the material so that

$n_1$ = population on $E_1$

$n_2$ = population on $E_2$

It is therefore :

An artificially provoked state where there is a greater number of atoms in the stimulated state than in the fundamental one. To produce such an inversion, we must proceed with a kind of pumping of the energy (in the crystal, for example) so that many atoms pass to the superior state.

It is obvious that this pumping (photons emitted by a flash, for example) must be extremely quick and occur close together because the atom carried on superior energy will only remain for a very short time and in several millionths of a second, will return to its fundamental state. It is not in a state of balance and returns to one asymptotically and by a close time constant.

The little T or : "relaxation time" of the system plays an important role in the dynamic theory. It depends on the quantum system and its environment. We will obviously try to find a very weak turnaround time in relation to the relaxation time.

A good example of this turnaround is the optical pump conceived by the physician KASTLER (ENS) :

Let us consider a quantum system at two levels (I) and (II) and place it in a magnetic field which will reduce the levels. Suppose that (I) divides in two and (II) subdivides in four. We said that not all of the transitions were allowed. Let us illuminate the recipient containing the quantum system with a variation $\sigma^+$ whose frequency corresponds to transition n°4. Through absorption, the systems at level $I_1$ will climb to level $II_3$ from where they will fall back, some by transition n°4 on the departure level, the others by transition n°2 on level $I_2$ irreversibly.
(drawing 37F).

It is clear that this method which pumps N system per second at level $I_1$ while the emission only returns $\frac{N}{2}$ system, will empty level $I_1$ to the benefit of level $I_2$. We will thus realize a population inversion between levels $I_1$ and $I_2$ (drawings 37 e and f).

It is often convenient to introduce a parameter to characterize the population of the two levels. It is the "generalized temperature" (also called Spin's temperature) defined by :

$$T = \frac{h\nu}{k} \frac{I}{Log \frac{n_1}{n_2}}$$

If the system is in a thermodynamic balance, this parameter coincides with the thermodynamic temperature measurable with a gas thermometer. In the absence of balance, this parameter has no themodynamic significance; it simply constitutes a procedure to note the difference in population. Of course, it can be positive or negative but never zero. The transition from the positive “temperatures” to the negative ones is done by infinity…
It is advisable to remember that the introduction of the generalized temperature is a convention and that the appearance of the “negative temperature” is by no means in opposition to the third thermodynamic principle which requires that absolute zero constitute a limited temperature.

### II – 5 – 6 – Importance of the stimulated and spontaneous emission

Using the relations of BOLTZMANN and PLANCK, we can say that they give us this relative importance. In the visible hertzian spectrum we can disregard the spontaneous emission and write the equation in the form

$$\frac{dv}{dr} = B(\surd).u.\,(n_2 - n_1)$$

This is interesting because it translates the coherent phenomenum as we have seen. The incoherent spontaneous emission will superpose itself on the coherence and this will be negligible.

In ultra-violet and in X we come up against this spontaneous phenomenum which hides the stimulus (problem of laser x-rays).

### II – 5 – 7 – How the laser operates

We directly use the data seen before.
The ruby is an aluminium atom made impure by chrome. This is what gives it its red color (drawings 38 a and b). At the top, the grey rectangle symbolizes a region where hundreds of levels of energy are so close together that they form a

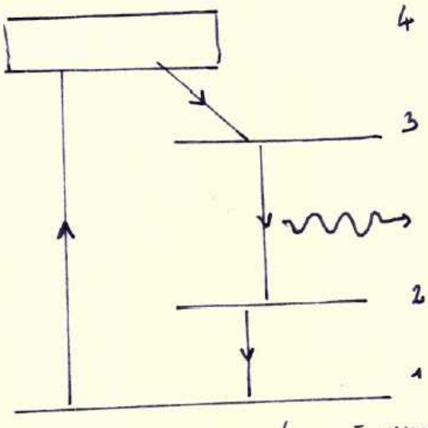
band of energy for which the spectrum of the chrome atom is practically continuous and not made up of distinct rays. (We saw the problem of these close energies in a previous chapter). It is the compact union of numerous atoms of a solid which gives this zone. Above this band of energy, the ruby is at a stimulated state (level 2). The transition between level 2 and the fundamental level gives the emission of the ruby laser. It goes without saying that a ruby atom having only one chrome atom would have no action because the emitted photon would be captured immediately by the arriving uncharged atoms.
No need to say that to have the stimulated phenomenum it must encounter other atoms and it is indispensable that it provoke a population's inversion (a large number of charged atoms). Once the population is inverted, the laser can function.

If the photon bangs into an atom that is already charged, the phenomenum increases, thus great intensity. If it shifts itself along the crystal, it encounters a mirror at the end so there is a backward movement and the same process. There will be successive reflection and an amplification of this phenomenum until the strong wave crosses the semi-silver-plated crystal mirror after 1/100ths of a second (drawing 38 c).

The laser described emits the light by flash. Thus there are applications for which the continuous light is necessary. Hence the necessity of an optical pump capable to maintain a population inversion. A good principle of the continuous laser is that it has four levels (drawing 39 a).
The pumping carries the atoms to the absorption band level 4 and the transition occurs between levels 3 and 2. The lower level not being the lower level, the population inversion is facilitated. All that must be done is to maintain this inversion. This is due to the fact that even if band 1 is very populated, the gap of populations 2 and 3 is weak and the inversion is easy.
Caution : to allow conditions for a wavelength, the length of the tube should be a multiple of the wavelength

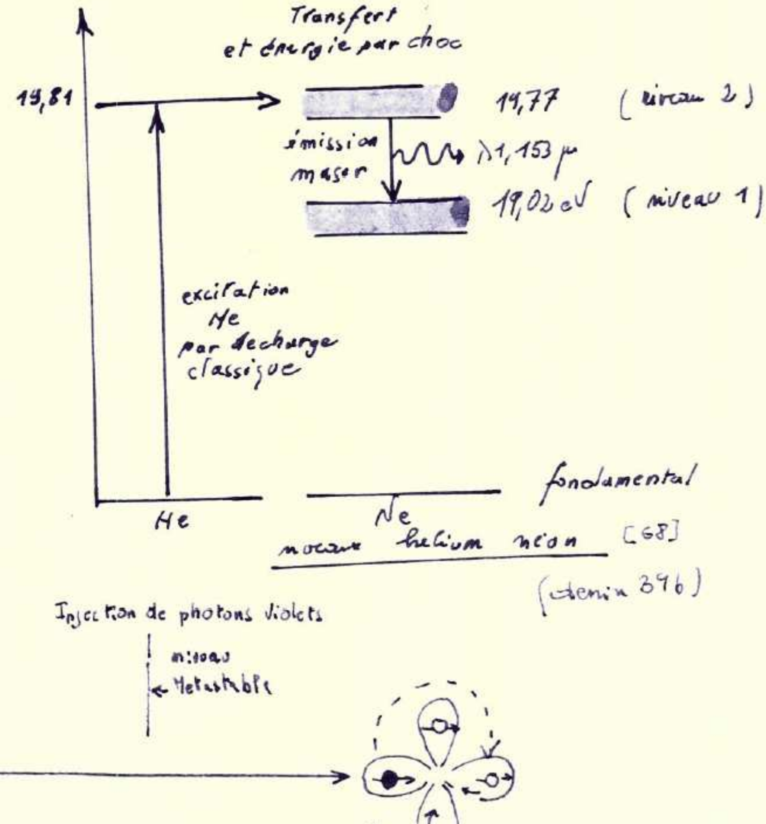
→ polishing

→ micrometric screw m → gaz / → liquid



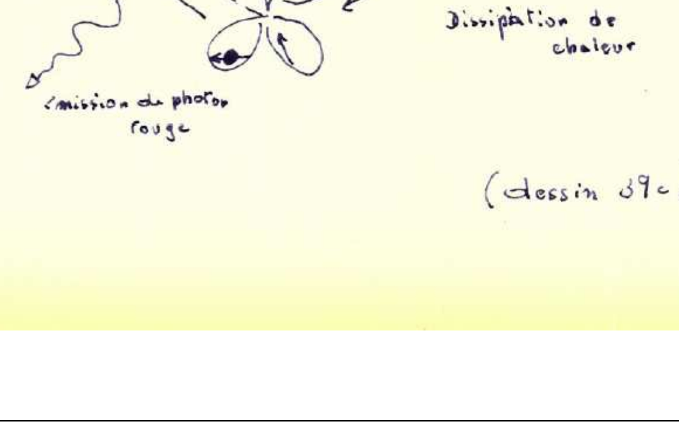

Laser à quatre niveaux [77]

(dessin 39a)




niveaux helium neon [68]

(dessin 39b)




(dessin 39c) [79]

Why is the laser light unique ?

It is emitted with four characteristics , superior to all other sources :
1°/ Intensity
2°/ Directibility
3°/ Phaseal coherence
4°/ Sharp frequency

1°/ - Intensity

Due to the stimulated emission, all the photons that follow one another are synchronized and in phase. Thus the amplitude and therefore the intensity of the radiation is maximally increased. Thousands of photons hit the same point in a tight row.

2°/ - Directibility

It can hit at a precise point. This is a direct consequence of the mirror since all oblique rays leave the system late more or less, but it draws out an atom when passing by and helps the phenomenum. Only the parallel beams leave.

3°/ - Coherence

The various waves constituting the beams are in phase just like hair of a curly lock. This function alone allows interference, the major role for us (see interference chapter IV).

4°/ - Narrowness

of the frequency band

Classic source : radiation of various wavelengths
Laser : an extremely precise wavelength. Why ?

The excited state constitutes in reality two precise and close states of the photon which will hit when stimulated, it will preferentially attack those which have its energy, therefore a closer wavelength (function of the distance separating the two mirrors).

## II – 6 – CHARACTERISTICS OF THE LASER AND THE MASER

### II – 6 – 1 – Why the laser ?

In order to justify the choice of one or another "coherent wave tool" in our study or future studies, we must explain each one according to its characteristics and its own future applications.

Today we can affirm that all the states of matter are likely to "laser" if one knows how to use it. In addition, these varied systems are generally complementary. Theoretic performances like high power, high coherence appear systematically incompatible.

We can therefore classify lasers either by their nature or by their application sector. Their only common characteristics are :

- an environment of a circuit amplifier (it is necessary to find a material that emits energetically at the frequency with which we want to work).
- a means of providing energy to this environment and to this circuit (it is necessary to find a means of inversing the population so that the stimulated emission surpasses the absorption)
- a renovator (a tuned circuit, a resonance cavity which intensifies the effect). The interferometer of PEROT-FABRY (which consists of two mirrors facing each other) is often used.

II – 6 – 2 – “Types of laser”

We have seen before that there could be three types of laser :
-solid laser
- fluid laser (gaz, liquid, ...)
- semi-conductor laser
There are three methods for charging atoms and molecules :

- The atoms can be lit intensely by a flash to bring them to a charged state. This is the method used by the solid laser.
- A discharge can be passed through a fluid
- A junction can be crossed between the semi-conductor by an electric current.

II – 6 – 2 - 1 Gas laser (fluid laser 1)

The three-level pumping method cannot be used because of the gas’s weak absorption of photons and because of the fine levels that require monochromatic pumping.

1°/ The gas with the active environment is held in a glass or quartz container, fitted with mirrors at its extremities
ex. : BELL in 1960, 90% helium and 10% Neon

2°/ The neon provides the wave streak
The helium excited by an electrical and magnetic field (H.F.) moves quickly and is charged.
The charged state of the helium corresponds to that of the neon so that each time the charged helium hits a neon that is in its fundamental state it can transfer all its energy to it. There is then what one could call progressive increase.

3°/ - The light is a beam that :

- is less powerful (than ruby) by a few milliwatts
- has an almost perfect coherence
- can be perfectly modulated (is telecommunicable)

This type radiates in the infrared. (1,13 $\mu m$)
This coherence is apparently due to what we can call the homogeneous aspect of the gas. (The isolated atom gives a temporary coherence).

4°/ Numerous gases can create a stimulated emission. The emission extends from approximately 0.2 μ m (UV) to 336,7 μ m.
It is divided into three categories :

Atomic laser : General continuous function at power levels somewhere between the microwatt and a few helium milliwatts. For example, neon is 10 milliwatts.

Ionic laser
There are 80 electrons in a mercury atom. If one or more electrons are expelled, it becomes a positive ion at an energy level that is different from the neutral atoms. These ions are a powerful source for obtaining wavelengths.
The first systems were inconvenient and fragile (overheating and hyper bombardment of the cathodes and the walls of the tubes). Today we can lessen this effect by using other ions (chlorine for example).
It covers the spectrum that is visible under ultra-violet rays, with a preference for blue-green, offers continuous power, is comprised of a few watts and in kilowatt impulsion.

Molecular laser (3 sub-groups) :
- It has a very short impulsion in nitrogen.

A ridge power of around a megawatt can be reached.
- Many stripes are obtained in the infra-red with carbon monoxide molecules and water (strong current, high tension).

- It is based on approximately 10 μ for working gases (carbon gas or nitrogen oxide).
It has a high yield.

Principle :
If a molecule receives energy, first there are vibrations then a rupture. If the energy increases, the "vibration" state is the high energy level.
The vibration's long duration (a few milliseconds) is what interests us.
We have : $CO_2$, N and H
The result : - discontinuous : from 1 Kwatt to approximately 10 Kwatts
- continuous : a few dozen watts

II – 6 – 2 – 2 – Solid lasers (see drawings 38 a-b and c) :

Solid lasers usually consist of an active environment, crystal or "doped" glass with neodyme (with an atom incompletely saturated).

The first models were done by MAIMANN and were in use in 1960.

They were made of :
- a resonance cavity of the PEROT-FABRY type
- a substance containing energy level with suitable spacing (such as a photon whose energy is that of an electronvolt). This energy relates to the COULOM interactions between the electron and the nucleus as we have seen.

To provoke a population inversion, a different method is used from that used in hyper-frequency masers because of the spectrum zone where we want to work. The spectrum must be spread to $E_3$ in E $E'_3$ thus covering the green and ultra-violet photons.

A substance has this energetic diagram : it's the ruby (0.05% of $Cr_2$ $0_3$) in an aluminium oxide base. This gives the chrome its values and its $CR_{+++}$ ion aspect.
Its value is of interest only if the spacing between the chrome atoms is large (drawing 40 a).

Handling principles

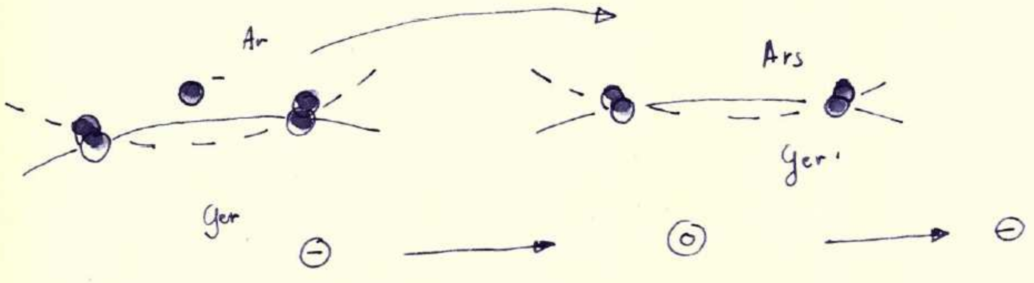
We inject photons in order to make the atoms from $E_1$ move to a higher energy level. The amplitude does not require a field application since it is provided by the atom's natural state. The un-matching electrons produce the hyper frequency action.

The three electrons will "use" optical photons which are thousands of times more energetic than hyper-frequency photons.
The three electrons need only turn at a certain angle to receive the hyper frequency photons (maser). In order to absorb the relatively high energy of the optical photons, the atom system must respond in a quite different way. The interactions between the chrome atoms and their neighbors, the three electrons (Spin) must move along the lines of a cloverleaf. The orientation of this orbit is a measurement of its energy. The angle is 45° for the violet photons, followed by a return, although not immediate, to a stable condition.

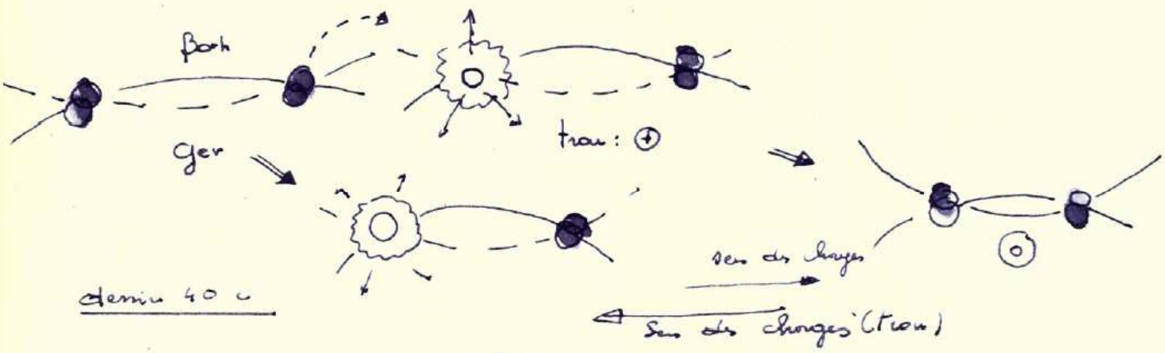
The speed changes when the magnetic interaction between the three preceding SPINs is adjusted (drawing 39 c).

- The three spins at the base level move in the same direction and change direction after absorption.
- When the atom returns, one of the dipoles "slows" and turns only 180°. The first passage up to the intermediate level results in a crystalline vibration (heat). The second passage emits the red fluorescent light of the laser.
- The time, which is very long for this type of phenomenum and leads to an intermediate state is simply a population inversion if there is a sufficient supply of charged atoms.

The radiated energy results in an almost parallel beam. HUYGENS's principle, with the addition of the radiation calculation, almost the total energy diffused along a cone.

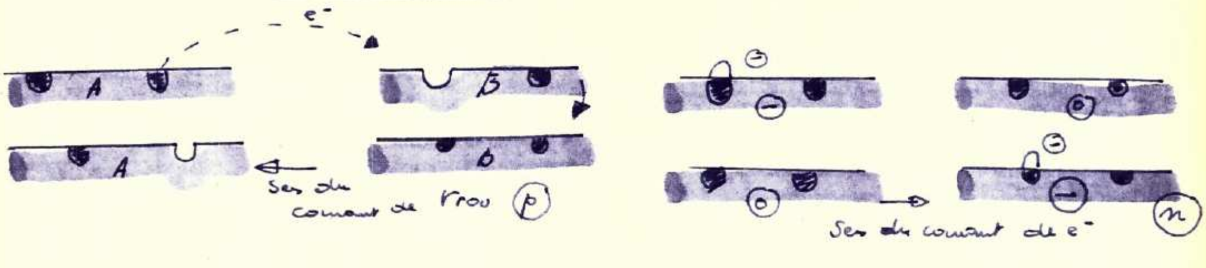



courant de $e^-$

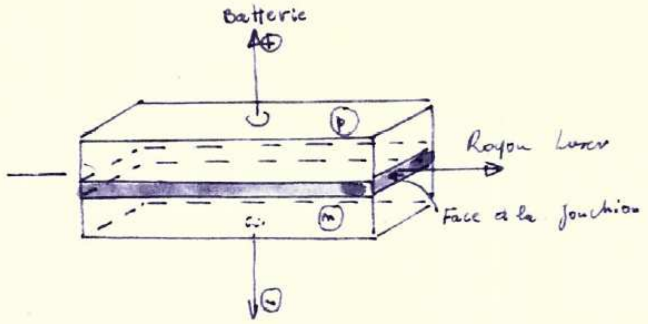



dessin 40 c

Courant de trou




dessin 40 d




Jonction p.n. dessin 40 e [74]

The operation is done by impulsion.
The energetic luminescence B is a very monochromatic source and is :

(The 0 angle is weak)

Apart from the great energy that this represents, another indication interests us with a lens system (100 million or more joules).

By emitting light energy during a few mono-seconds, we can detect the time and therefore the distance separating an object from the source. (This principle will be explored further in the following chapter). See YAGYTTRIUM and aluminium laser, the object of much research.

Other solid lasers exist (see chart). We note some interesting improvements :

1°/ To regulate the effect of pumping and to have the maximum population inversion based on the principle that the more mediocre the resonator quality, the larger the inversion, only a quick modification of the QO (characteristic chemical loss of a cavity) is needed. This is what the KERR cell allows (see specialized work).

2°/ The solid zigzag laser climbs to 100w during 30 mono-seconds (doped glass with a neodyium placed in zigzag). Each force is uniformly lit and has good cooling so that we can work in repeated impulsions without deterioration (see drawing 40 b).
This leads to a continuous current if necessary.
To sum up, these lasers have considerable power, mediocre spatial coherence and excellent temporary coherence.

# LASERS POUR PRODUCTION D'ENERGIE

| NATURE DU MILIEU ACTIF | TYPE DE POMPAGE | PRINCIPALES LONGUEURS D'ONDE | FONCTIONNEMENT CARACTERISTIQUE | PERFORMANCES TYPIQUES (1)<br>PERFORMANCES MAXIMA (2) | | | | INTERÊTS +<br>LIMITATIONS − |
|---|---|---|---|---|---|---|---|---|
| | | | | PUISSANCE | ÉNERGIE | DURÉE | RENDEMENT | |
| SOLIDES DIELECTRIQUES (VERRE ET CRISTAUX DOPES) | Optique (lampe ou flash) | 1,06 μ (Neodyme)<br>6943 Å (Rubis) | Impulsions, declenchées ou non<br>Fonctionnement continu (YAG) et impulsions à haute cadence | (1) 30 MW<br>(2) 1 TW<br>(2) 30 GW<br>(1) 10 W<br>(2) 100 W | 1 J<br>10 J<br>1000 J | $3 \times 10^{-8}$ s<br>$10^{-11}$ s<br>$3 \times 10^{-8}$ s<br>continu<br>continu | $5 \times 10^{-3}$<br>$5 \times 10^{-3}$<br>$5 \times 10^{-3}$<br>$10^{-2}$<br>$10^{-2}$ | + Très grande puissance crete<br>+ Impulsions brèves<br>− Faible rendement<br>− Faible coherence<br>− Fonctionnement continu difficile |
| LIQUIDES INORGANIQUES DOPÉS ($POCl_3$) | Optique (flash) | 1,06 μ (Néodyme) | Impulsions déclenchées ou non<br>Haute cadence possible. | (1) 30 MW | 1 J | $3 \times 10^{-8}$ s | $10^{-2}$ | Substitut possible du verre au Neodyme<br>+ Renouvellement du milieu par circulation<br>− Toxique, corrosif |
| GAZ MOLÉCULAIRES ($CO_2$) | Electrique (décharge) | 10,6 μ ($CO_2$) | Fonctionnement en continu ou en impulsions | (1) 50 W<br>(2) 1 KW<br>(2) 10 KW<br>(1) 10 MW<br>(2) 100 MW | <br><br><br>10 J<br>100 J | continu<br>continu<br>continu<br>$10^{-6}$ s<br>$10^{-6}$ s | $15 \times 10^{-2}$<br>$25 \times 10^{-2}$<br>$15 \times 10^{-2}$<br>$17 \times 10^{-2}$<br>$10 \times 10^{-2}$ | + Rendement élevé grandes puissances continues<br>+ Technologie relativement simple.<br>+ Grandes puissances crête (pression atmosphérique)<br>− Encombrement parfois important |
| | Chimique (réaction) | 3 μ (HF)<br>10,6 μ ($CO_2$) | Fonctionnement en impulsions | Experiences de laboratoires | | | | + Source d'energie de pompage autonome |

# LASERS "A VOCATION ELECTRONIQUE"

| NATURE DU MILIEU ACTIF | TYPE DE POMPAGE | PRINCIPALES LONGUEURS D'ONDE | FONCTIONNEMENT CARACTÉRISTIQUE | PERFORMANCES TYPIQUES ( )<br>PERFORMANCES MAXIMA ( ) | | | | INTERÊTS +<br>LIMITATIONS − |
|---|---|---|---|---|---|---|---|---|
| | | | | PUISSANCE | ÉNERGIE | DUREE | RENDEMENT | |
| GAZ (ATOMES OU IONS) | Electrique (décharge) | De 3000 Å à 20 μ<br>6 328 Å, 1,15 μ } He-Ne<br>5 145 Å, 4 880 Å } $A^+$<br>4 416 Å $Cd^+$ | Regime continu | (1) 1 à 100 mW<br>(2) 100 W ($A^+$) | | continu<br>continu | $10^{-4}$ à $10^{-3}$<br>$10^{-4}$ | + Tres grande coherenc [redacted]<br>+ Prix et encombrement relativement faibles<br>− Faibles puissances bas rendements |
| LIQUIDES ORGANIQUES COHÉRENTS (RHODAMINE) | Optique (Flash, laser) | Tout le visible et jusqu'à l'UV<br>0,4 à 1 μm | Régime impulsionnel avec cadence de repetition. | (1) 3 MW | 0,1 J | 30 ns | | + Longueur d'onde reglable<br>+ Renouvellement du milieu par circulation<br>− Fonctionnement continu difficile |
| DIODES SEMI-CONDUCTRICES (ARSENIURE DE GALLIUM) | Electrique (courant d'injection) | 9000 Å<br>0,6 à 0,9 μm | − Regime impulsionnel<br>− Régime continu à faible puissance<br>− Modulation haute-frequence directe possible | (1) 10 à 50 mW<br>(1) 50 W | <br>$5 \times 10^{-5}$ J | continu<br>$10^{-6}$ s | $10^{-1}$ | + Tres faible encombrement<br>+ Bon rendement<br>+ Emission facilement modulable<br>− Coherence faible<br>− Technologie delicate pour fonctionnement en continu à Temperature ambiante |

(dessin 41) [62]

II – 6 – 2 – 3 – Organic laser (fluid laser 2) :

Some organic molecules can be charged and give off light. They dissolve in a liquid solvent or can be covered with a solid matrix (Plexiglass).

What is interesting is that the radiation covers the entire visible spectrum. Numerous product exist (Photo-tracers are one).

II – 6 – 2 – 4 – Liquid laser (fluid laser 3) :

Ions (notably neodymium) can also be introduced into a solution in certain liquid environments in order to obtain laser emissions of around 1.
The functioning principle, the pumping techniques and the characteristic performance are practically comparable to those of a laser of neodymium doped glass.
The only important difference is that the liquid can be put in a quasi permanent circulation to efficiently evacuate heat dispersed during pumping. This is how a fairly high rate of impulsion was obtained (50 to 100 impulsions per second).

But these liquids are chlorine solvents and are generally toxic and corrosive (this is the case with phosphorous oxychlorine PO $cl_3$ and the selenium oxychlorine Se $OCL_3$) which makes the technology of these lasers quite delicate.

It can be an excellent substitute for glass and neodymium if we want to increase the energy and the power of the ridges of the large lasers [82]. At very high power, we can obtain plasma ($4^{th}$ state of the matter) [86] which has high energetic values.

II – 6 – 2 – 5 –Laser connected to a semi-conductor [79-80] :

The laser effect in the semi-conductor diodes was obtained in 1962 almost simultaneously by several research groups (IBM). They used Galium arseniure.
-overall dimension : a few cubic millimeters
- yield : 60%
- tension : 2 v to 1.5 v

What is extraordinary is that until 1968, a 10% yield and impulsion rate was achieved.
Today we are beyond this stage (Bell Telephone).

A semi-conductor is an intermediate between a conductor and an insulator [74]. This is due to the 5$^{th}$ electron, for example, of the arsenic which does not match and which therefore becomes free to drive the electricity. If, on the contrary, a BOHR atom (3 electrons) is opposite a germanium atom (4 electrons), one electron will be missing and one of the germanium electrons will be a space waiting for an electron, or hole. We can imagine like the passage of an electron, a passage of hole resulting in a current of hole (drawing 40 c). The first ones are type n, the second ones are type p.

One or the other can be doped at will. The encounter of two p's and n's is called a pn junction. This junction has many properties. We will limit ourselves to the emitting and the absorbing electrons.

If this is exposed to a light, electric conduction occurs. (For example, the hv of radiation puts a free electron in a hole). If this radiation has no energy, a ray will also be emitted. This is the secret of the pn junction.

With the junction laser, the electrons are injected by force into the n region (drawing 40 d) by an electric source and will go towards junction p where again the holes are pushed towards n.

By joining with the holes, the electrons lose energy (in the form of heat and molecular vibration as well as in the form of a photon) or it does so directly in the form of a photon which is the laser. The effect is increased by polishing the functions (mirror in cascade).

Advantages [74]

- no need for an auxiliary pump because the injection is done directly by the electrons
- can transform 100% of input power into radiation (temperature factor)
- radiation frequency charged at will by adjusting the chemical composition of a semi-conductor or by varying the temperature.
- the power is a function of the current (drawing 40 e)

Various apparents [73]

- homojunction p + p or n
- simple heterojunction (large space) p + p
- double heterojunction (larger, undifferentiated space).
- double-emission heterojunction (ex. 0.7280 and 0.8450 μm)
- red and infrared function (0.6280 to 0.900 μm)

materials [In As] [In np] [In 6a (As)] [In Asp]

Note : some lasers can be pumped by an electron beam [73] [Zn (0.32 μm)]

II – 6 – 3 – Summary chart

(see drawing 41)

## II – 7 – DISCUSSION

The examination of the main theories of the atom's energetic consitution, electron variation in the atomic cloud.

The examination of the main theories of the atom's energetic makeup have shown us that each electron presents four precise and correct quantum numbers. Each variation of these numbers, that is to say the passage from one quantum number position to another, generates an energy variation that varies more or less according to the number involved.

This energy variation can generate a radiation that is interpreted according to two inseparable theories : by an electromagnetic quantum wave. This wave has a variable energetic value that corresponds to the variation structure value.

Having left the atom [24], this wave can take this energy partially or totally before reaching his goal. The ray's coherence arrives. The values in x points are given in lux and candlepower.

Based on EINSTEIN's work we can find an almost perfectly coherent wave that has extremely interesting properties.

The emission charged with population inversion allows this [25]. The maser laser enables to obtain this wave [26]. It does so according to different processes. We will choose one of them.

We are able to understand the hologram but first we must reduce our choice to the assimilation possibilities of the organism. (see the following chapter).

## II – 8 – CONCLUSION

We choose a laser with the following characteristics :

Intensity : it is not necessary for our impression. However, this could be interesting for the device's accessory applications (bistoury, coagulator).

Directibility : it is absolutely necessary. Conduction would perhaps be done by the fiber.

Coherence : it is absolutely necessary (hologram).

Frequency : the wavelength is a function of the organism.

We have, therefore, weak intensities, maximum directibility and coherence, frequency, biological function.

The He neon laser seems identical.

# THE RAY'S EFFECT ON THE ORGANISM

## Is it dangerous or not ?

- **INTRODUCTION**
- **SYSTEMATIC ACTION**
- **PROTECTION**
- **THE LASER IN DENTISTRY**

*I wish to thank Professor Dumas for his help with this chapter.*

# CHAPTER - III –

## III – 1 – INTRODUCTION

The sole interest for us lies in the answer to a precise question : will the laser we choose have one action on the mouth and on the body ?

At the beginning we could concentrate our study on one laser and, according to its data, decide if it is dangerous. But if future studies lead us to change the origin or if a new laser is proposed, we would have to reconsider these data.
To partly lessen the impact of failure, we will consider the effect of laser in general on the body.

### III – 1 – 1 – Action mechanism

First of all, we must study by which mechanism the beam acts on the living matter. The most apparent mode of action is the thermogenic effect. In addition to very localized burning, it can even vanish tissues.

If we want, we can use the ray in an overall manner and indiscriminately burn all the tissues, but we can also be selective. Most chemical substances, in particular those that make up the organism only retain light of a certain color by the selective absorption phenomenum. The laser's light is very pure and only contains one single fundamental (red, blue, green or yellow) according to the type of equipment used to produce it. Consequently, if we choose an emitter whose light is precisely absorbed by a single substance; this substance will be destroyed without affecting in any way the surrounding substances. This is why we can obtain the destruction or the denaturation of the living organism of such a cellular component without killing the cell.

Electrical action

Another biological action resides in the electrical field that accompanies the laser beam. This beam can reach values of 1000 billion volts per meter. The electrical field that unites the electrons and the nuclei in the atoms is about the same size. We imagine that radiation can act on the physical constants and even on the architecture of the environment it travels through.
This involves modifications of their conductibility or their di-electrical consistency, the opposition of free, very toxic radicals for living cells, shake-up of the balance of certain chemical cellular reactions, even the remodelling of certain molecular systems.

Mechanical action

The laser also acts on living matter in a purely mechanical way but producing from the point of impact shock waves provoked by the considerable radiation pressure. These push the cells by forming an actual crater or by orienting the molecules toward the propagation of the beam. These shock waves create very sharp ultrasonic phenomena which, by transmitting in the surrounding environment can, from a distance involve lesions at the level of the living tissues.

Non-linear effect

Lastly, with the laser we see effects which have never been effectively obtained with conventional lights : non-linear effects.

Traditionally when a light is pure from a color point of view (i.e. monochromatic), its color does not change whatever the environment it passes through.

On the contrary, under certain conditions, even the color of the laser beam can change. Can a green beam generate an ultraviolet one with the whole thing coming from a red beam ?

If the red is somewhat harmful from the biological point of view, the ultraviolet that is emitted under certain conditions is extremely dangerous for living cells. Also, these same non-linear effects can provoke the appearance of acoustical waves (the BRILLOUIN effect). We must take this phenomenum into account although it is not very well known.

Beginning in 1964, the work of TOMBERG allowed the classifying of the laser's biological effect in 4 categories: thermal, electrical, chemical and kinetic. TOMBERG used an inversed microscope previously used for probing with the laser by radiation of plasma citrated by a tissue cutting.

Particular effects were discovered and specified by a Russian team (CORODEC'KYJ). They discovered elastic oscillations on biological materials (ruby laser). By successive actions they found that free radicals seemed to be visibly linked to pigmentary compounds.

MENDELSON underlined with special systems, shock waves and intense heat releases but strictly limited to the radiation's point of impact and consequently of doubtful biological importance except on the retina (skin and muscle are semi-transparent for the laser's radiation).

COLDMANN studied the biological effects of radiation focussed on high energy (detachment of the retina).

There is a whole series of work on the biological and medical role of the laser (SMART – TOMBERG – VISHNEVSKIR – FINE). BURKHALTER specified the ways of displaying the organic and mineral effects. He also studied impulsions of mechanical effects and the backing up of the target and thereby described a way of measuring these effects.

## III – 2 – SYSTEMATIC ACTION

### III – 2 – 1 – Succinct plan

All this can appear confusing but the idea was to explain the biological studies are very extensive and are not limited, as one might expect, to simple effects of observation.

Now we will divide our biological and medical study into two parts:

- Influence of the beam on the various parts of the organism, successively:

a) at the molecular level :

- enzyme and enzymatic reaction
- endocrinal system
- reproduction, we will not develop this notion further because it is not important to our study, considering our field of action.

b) at the cellular level :

- action on the nervous system : - anatomic
  - physiological
- action on the circulatory system
- action on the epithelium tissue and its derivative
- action on the tissues

We will divide our study according to the cellular organites and will approach the problem of reproduction and tumors at the cellular level.

- action on teeth and dental tissues

We will expand on this section by looking at what previous studies have discovered regarding the nervous and circulatory systems (tissues and organites).

Having generally established the effect of the laser ray on an organism, we will try to explain its various applications in our field such as surgery, prosthetics, biology, paradontology, orthodontia and of course, endodontia.

### III – 2 – 2 – The molecular level

#### III – 2 – 2 – 1 – Action on enzymes (drawing p. 131)

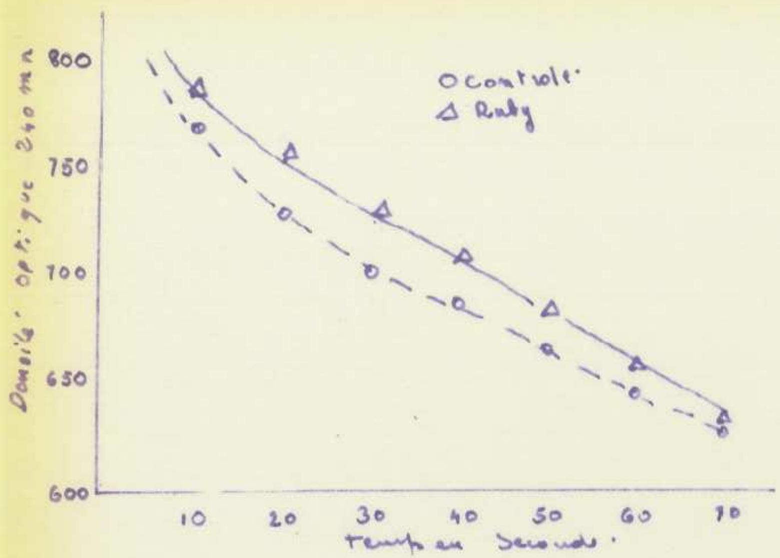
The first studies were done on tissues which are very diverse materials.
However, their effective range never misses enzymes, a specific group of substance or micro-organisms [115]. We note in particular studies on respiratory cells [116], micro-radiation from the ruby laser [117], isolated culture cells of colored tissue in a vital state by the JANUS B green and the effects on dehydrogenic activities.
There are several different conclusions that we can make for [118-119] BAR IGELMAN. For many years he studied the effect of radiation on the non activation of enzymes. Since 1879, when DONNEZ proved that zymase could be destroyed by the sun, we have made much progress….The effect can also be linked to the pH and is a function of the wave's features. The rays actually are responsible for the non activation or destruction of the enzyme. Their effect can also change its optical properties, sedimentation speed and solubility. The effect is either direct or indirect but it is the effect of ionisation that is responsible.

The result (see drawing) is a small or even unnoticeable decrease in enzymatic activity, usually denaturation but this is tied essentially to exposure time: the effect resembles that of X-rays.

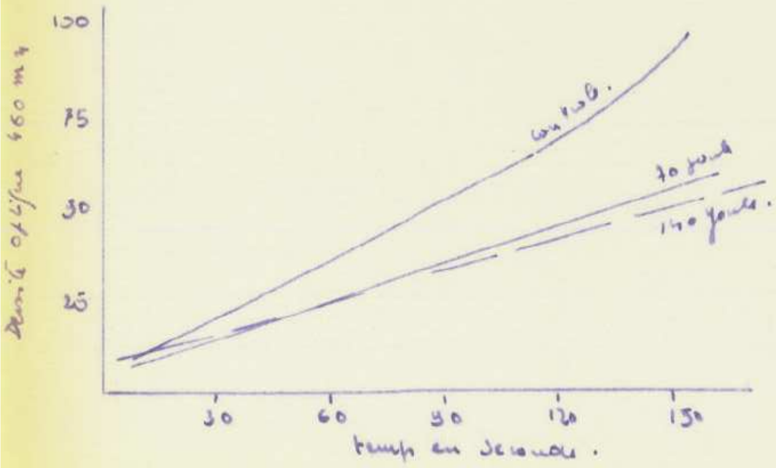
Only the peroxides prove to be inactivated (45 to 85 joules). In reality, FINE's studies tend to generalize the lower activity rate and tie it to quaternary structure which would be denatured.

#### III – 2 – 2 – 2 – Endocrinal system

There are only a few studies because we are not concerned with this area [120]. We will mention only hydrocortizone in the final chapter.

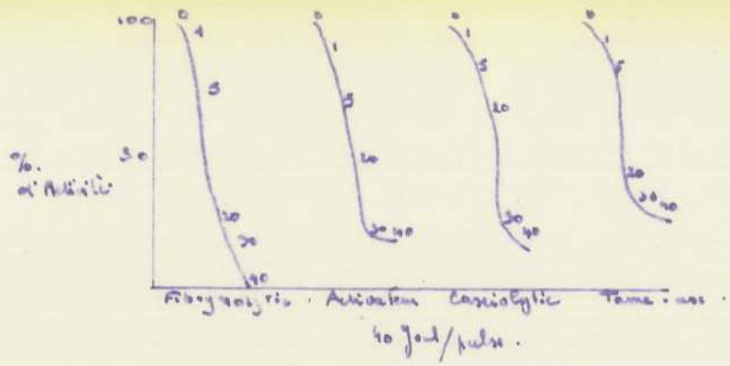


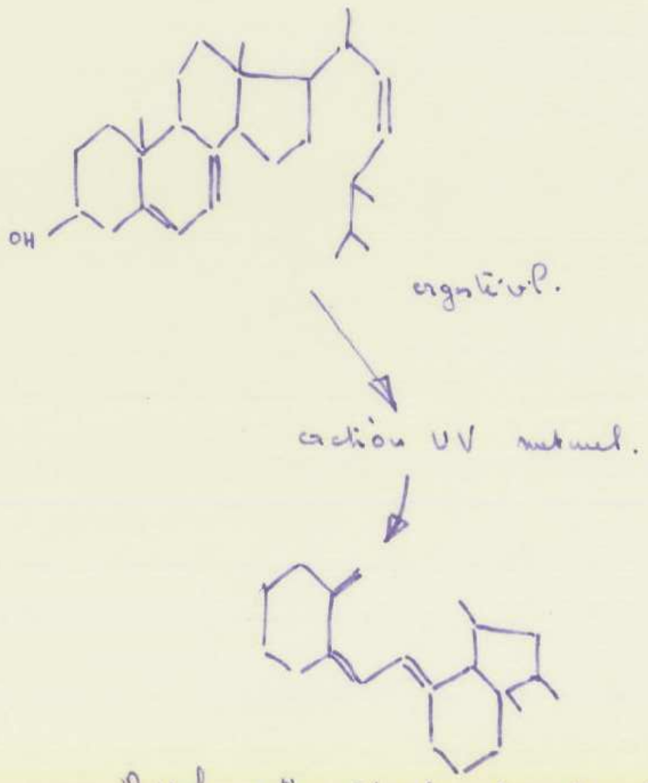

catalase.




oxidation (peroxidase)

Inselmann.




Roffel ; action simple sur ergostérol

### III – 2 – 2 – 3 – Reproductive system

Here again, a few studies but of little interest [121-122].
Local radiation of a 12 to 14-day-old embryo (exposed uterus) or an 18 to 20-day-old rat foetus produces lesions without rupturing the uterus or the amniotic sac and without loss of amniotic fluid. Studies with radiated spermatogenesis seem to lead to the same conclusion [123].

## III – 2 – 3 – Cellular level

### III – 2 – 3 – 1 – The nervous system

The effect on the nervous system extends to :
1°/– the central nervous system
- the nerves
- the peripheral organs

2°/– the functions

#### III – 2 – 3 – 1 – 1 – Effect on the central nervous system

Various techniques have been used and with each publication the author carefully establish their techniques [124]. For the most part, the lesions observed on cerebral structures are usually [125] localized at the point of impact and vary according to various structures (see [127]).

- lethal intracranial hypertension (high energy)
- cerebral edema [128-129]
- necrosal hemmorhage
- neurological and behavioral aberrations
- secondary effects which are much more serious than the primary ones [130]
- consequences of thermal effects (which remain localized in dead mice or guinea pigs)
- consequences of ultrasonic waves involving secondary effects [131-132] or induced ultrasounds.

Some solutions from these studies are proposed. See that of scanning with continuous emissions of 177° wavelengths [133].

#### III – 2 – 3 – 1 – 2 – Effect on the nerves

Through radiation of the isolated sciatic nerve of a frog by a high-powered laser $4.10^{16}$ w/cm², we obtain tissue eruption at the point of impact; rupture of the capsule with protrusion of nerve fibers. There are alterations of the myelin sheath and ascomes and full or partial blockage of the propagation of potential effects [139].

### III – 2 – 3 – 1 – 3 – Effect on peripheral organs

Hearing

We have spoken about the secondary ultra-sonic consequences of laser radiation. Based on this and others sources, researchers discovered the effect on the cochlea [140]. Very high doses have a harmful effect but its interest lies in its stimulative aspect [141 - 142].

Vision

This is a very large chapter because there are numerous medical applications to conclude our work but we will not detail them here. We will limit ourselves to studying the effect of laser beams on the various parts of the eye.

We will first attempt to recognize the exact effect of the beam on the whole eye in order to point out the dangerous limits.
The weak energy [143] seems to result in a continuous wave and some non disturbing entoptic images.

Studies were done from 350 to 1,500 mm of transmission through the eye environment and reflection and absorption of pigmentary epithelium of the retina and the choroid of humans, rabbits and monkeys [144].Using the data of DAVIES [145] and other authors, this lead to less intuitive research than that of ZARET [146] whose precision has been followed since 1961. A single error of 0.5 ms in raised energetic density, like that of the laser, is enough to produce instantaneous thermal lesions on the pigmented resin and the iris. In 1966 JONES [147] stated that the intensities of the various rays macroscopically provoke corneal erosions, crystallin ruptures, formation of bubbles and hemorrhaging of the vitreous humor. Histologically it produces large lesions in the pigmentary epithelium and the choroid, followed by detachment and degeneration of the retina located around the exposed area. The effect of the KRYPTON laser or other photocoagulators lead to opposition of the use of many devices [149-150].

A mathematical model describing the probability of ocular damage achieved by a pulse laser beam and the function of the atmospheric optical parameters was established [151] and measuring methods were perfected [145].

The laser not only provokes burns. We have seen the effect of ultrasounds on the ears. These elastic waves spread even to the occipital bone ! [152 -153] and are not thermal. The formation of bubbles in the vitreous humor would be due to these impulses. An experimental drawing, an oscillogram of the phenomenum established the correlation in time between photonic laser impulses and ultrasonic oscillation in the vitreous environment.

Effect on "lipids"

We submit as evidence ultrasonic vibrations provoked by the laser in the vitreous body and other environments with cavitation phenomena no matter what the environment's transparency [155]. Modifications in the refraction index of the acqueous and vitreous humor were noted [156-157] the same as temperature variations [158] as well as variation of the electrolyte of endocular liquids [159] and in particular the relation $\frac{Nc^+}{K^+}$ in the acqueous humor and the crystallin following photocoagulation.

Effect on the iris

There is a definite effect on exterior contraction [157] but also and especially on pigmentation. This guiding idea reoccurs in pigmentary bodies [161].

Effect on the cornea

Through diffusion studies we find symmetrical distribution of the superstructure [162] but what interests us is whether the effect is dangerous or not.
Radiation of 0.1 w/cm² for 30 minutes does not provoke any clinical or therapeutic lesion [163] in a rabbit. Various morphological modifications (basal and epithelial

membrane, cornea and stroma) are disintegrated for supraluminary energies and the area around the threshold. Very high doses must be used to obtain lesions in the visible or almost visible part of the cornea [164].

The effects can be classified as [165] :
- strong energy dose : necrotic perforated corneal ulcer;
- weak energy dose : no effect.
Between the two non-penetrating necrotic ulcers are the most superficial corneal layers.

It should be noted however [166 – 167 – 168 – 169 - 170] :
- with radiation 6943 Å 4 joules/cm² we observe a mitosis disorder on the cornea;
- a very powerful carbonic gas laser creates thickening of the cornea (fusion of the corneal lamellas at the periphery, revealed by the existence of amorphous focusses along the collagen fibers);
- visible and dosed impacts of the UV and $\gamma$ can be found with the ruby laser.

Effect on the crystallin
Various wavelengths give the following results [171] 10600 Å (IR) a greater damage than with green rays (5300 Å). The green rays act on the equatorial zone of the crystallin and sometimes create a rupture of the capsule hence the explanation of the anterior epithelium. Infrared rays provoke an annulary cataract. This annulary cataract [172] is characterized essentially by a drop in calcium as in a galactosic cataract but on the contrary of tetanal or cryotic senescence.

Effect on the retina
The analysis which introduced retinal lesions in the laser ray, has been described by numerous authors [183]. Studies were first done on the human eye [174]. This lead to the creation of a threshold of retinal lesions [175].

CLARKE [176] and COLL determined the local temperature at which retinal lesions form : 9 to 10°C.

A mere 1 to 2 focused mW on a 10 μ diameter for 250 ms is sufficient to cause irreversible damage.

From these observations [177] one immediately suspects the presence of individual grains of melamine. Physical characteristics of pigmentary epithelium, thermal stability and optical properties of the new model melamine grains are studied. This theory is based on energy absorption by granules of 1 μ in diameter and on thermal conduction between these grains and the neighboring essential retinal structures. These melamine grains [178] are considered as the primary absorption site (site of the greatest energy absorption per unit of volume). The effects on retinal vascularization [179] led to more involved studies. Histological studies of experimental lesions were undertaken.

1°/ - Lesions in which the junction layer between sensorial cells and pigmentary epithelium was conserved [180].
2°/ - Photocoagulation and study of corresponding increases in temperature [181].
3°/ - Lesions of continuous or pulse visible red spectrum [182].

Histological studies led to research of anomalies in the electro-retinogram from 1966.
The results were descriptions of possible reactions provoked by the optical tractus [183] and by a photic stimulation on a cat which has a lesion. These modifications [184] appear reversible under certain conditions. Continuous applications of bright light (rat) led to the study of two processes: deterioration – regeneration which are supported by tissue (the visual pigment).
Finally, we note transitory changes [185] in the electroretinogram and discharges of the optical strip after laser radiation. NOELL's histopathological result [86] shows a large degeneration in visual cells and pigmentary epithelium, confirmed by a decrease in amplification of the electroretinogram's waves. This demonstrates the existence of a correlation between the effect of light and the eye temperature which explains the importance attached previously to temperature.

Thermal lesions can go undetected [181] at the beginning but the decrease in visual activity with visible lesions provoked by the laser and the photocoagulator have been mentioned [188 -189- 190]. The photocoagulator allows to treat [191 - 198] retinal detachments and ocular tumors and create artificial pupils. This is therefore [193] the description of enucleation of a malignant melanoma. We know that separation of one of the retinal layers irreversibly leads to blindness. To reattach the retina we heat or otherwise irritate the retina and the underlying tissue so that they are joined by a common scar. The laser has the advantage of being very precise and allows one to work in a fraction of a second [102] and it does not generate any temperature which eliminates the need for anaesthesia. Choroidal-retinal cauterization leads to absolutely tiny visual losses [103]. It should be noted that “constituted” detachment (liquid film) does not relate to photocoagulation anymore. It has been a long time since Professor Gaillard’s Paris team radiated the eye of a rabbit and cut the eye with a microtome.
The device or ophtalmoscope is currently used satisfactorily.

### III – 2 – 3 – 1 – 4 – Discussion [194 - 195]

The choice of wavelength to be used is determined according to two conditions.
First, the light must not be absorbed by the cornea, the crystallin or humor of the eye, the graph shows that wavelengths of 400 – 900 Å and of 10600 Å are the least weakened by these tissues. Secondly, the wavelength used must be absorbed by the tissues located behind the retina for an average of 4000 and 12000 Å, the maximum being 5000 Å. The ruby laser (6943 Å) is the best. The Helium-Neon 6328 Å also creates infrareds and neodyme 10600 Å provokes cataract.

Energy is at 0,008 joules. It increases or decreases the diameter of the scar, 0,1 mm corresponding to approximately 0.11 joules is the most efficient.

### III – 2 – 3 – 1 – 5 – Behavior

First of all we must mention that KIRBY, KOVANIC and STURDIVAN made a great systematic study in order to find the exact level of mortality [197] using a ruby laser.

They give the dose in joules, the force in grams and the behavior’s response immediately or after a certain time. The doses go from 18 to 204 joules, this is represented by a diagram. They deduce from this that the mortality doses or loss of encephalographic activity is essentially tied to the doses and exposure time. They determine $DL_{50}$ and the activity threshold.

JOHN did a study on insects (ATT, proteins, uric acid) and did not come up with any major conclusions [196]. We base our study essentially on the work of DUMAS [198].

FINE [138] claims that radiation of 100 joules for 1 ms at 6943 Å leads to 75% mortality in 24 hours. Surviving animals had sense and motor changes.
For DUMAS [198] the 6943 Å ray increased cerebral activity (20 joules in 1 ms) in white rat. “This effect reaches a threshold and a maximum” a few hours after radiation.

Neither the observed modifications or the autopsy revealed any lesions or microscopic hemorrhaging of the encephalon (20 spaced emissions of a 3 minutes, one series separated from the next by 30 minutes) (drawing 43 a).

#### III – 2 – 3 – 1 – 6 – Conclusion : Protection of the nervous system

Parameters [189] are essentially the surface condition, transparency, refraction index, ionisation potential and photonic conductibility.

DUMAS’ s article is very optimistic about our possibilities of action. The eye is the most exposed organ in the nervous system. It is dangerous to look directly at the source and so is the interception of a reflected beam [189] because of the retina and crystallin focusing.

At a symposium in Washington the biological effects of the laser on the eyes were discussed [199]. Factors regarding the laser and the eye were separated [200] and compared to other rays [201].

FRIEDMANN [202] proposed a program of ophthalmic protection. No retinal lesions were found out of 195 people in a laser laboratory.

Let us say that there is a notion of dose and of shock [203]. Doses of limited exposure are listed in a chart [204] as well as data for the ruby and neodyme laser (not of interest to us) [205]. In 1965 easy-to-use filters were proposed [206].

A mechanism comparing the human eye to the rabbit eye was submitted and a iena glass was found.

These comparisons are interesting for potential research. The limit is 200 joules. The degrees of passage are described (drawing 43 b).

Therefore pulse radiation that the hologram requires must have weak power. Protection does not seem indispensable in this case but remains easy even at the weakest organ's level that is to say the eye. Protection will be linked to the wavelength used (see 77, p. 128) and exposure time.

### III – 2 – 3 – 2 – Effect on skin (77, p. 130)

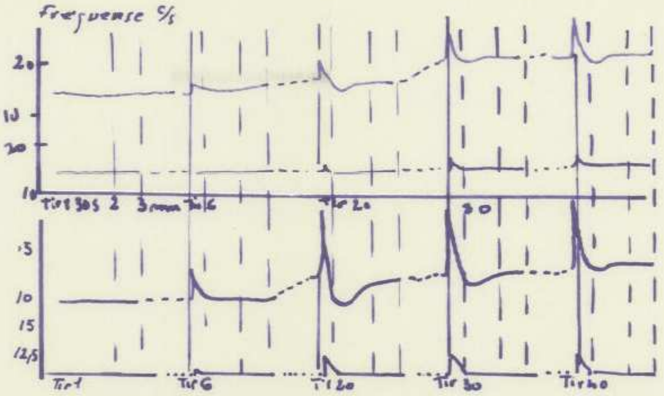
Little reaction results from absorption by high energy. The threshold is 25 joules per cm² for white skin and is weaker for a dark spot on the skin (mole, tattoo).

A beam focussed on the skin can, despite everything, provoke serious burns [189] SOBOLEN [98] greatly increased the laser's role regarding tumors.

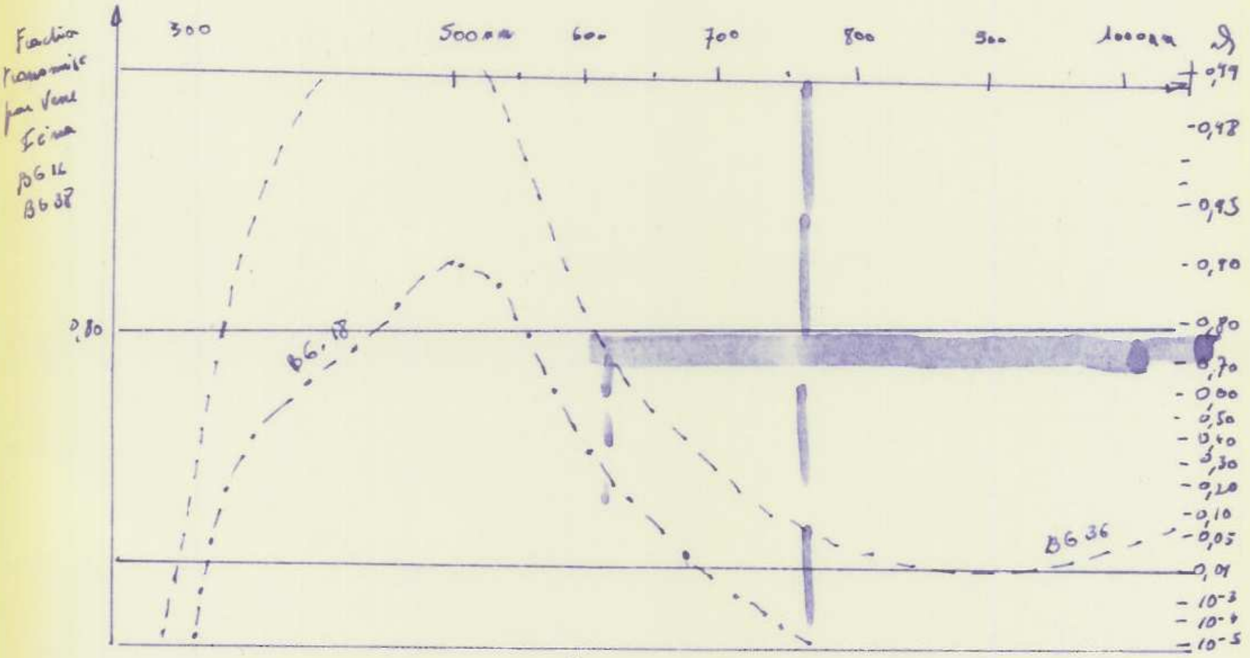
According to publications, a continuous impulse of weak intensity can cause inflammatory phenomena in a mouse and even destruction of pilose follicles and epithelial atrophy. In some mice, there was necrosis of the liver and the small intestine [207].

Weak doses seem to stimulate the division of pilose follicles different from those at larger doses [208 - 209].

During radiation of the skin, necroses seem to be more abundant on the most pigmented cells (black) including melanocites [210].

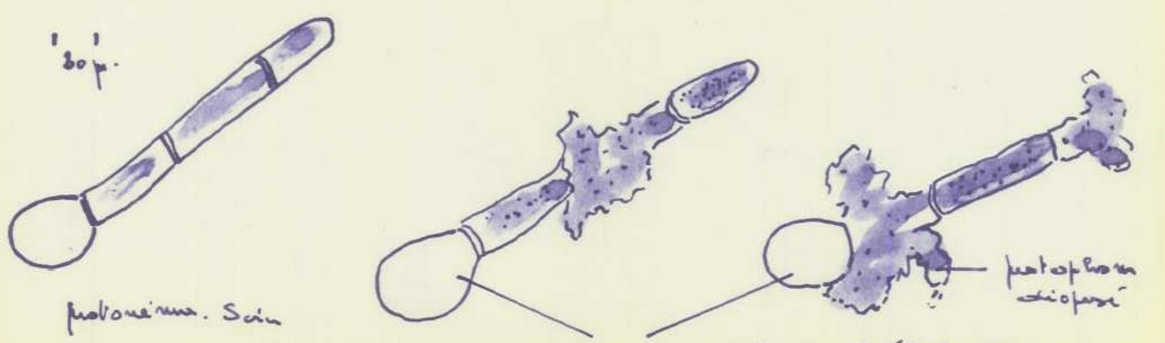



dessin 43a [198]




690 nm : 6900 Å
12 000 nm : 12,000 Å

dessin 43b [206]




dessin 43c

For the FINES-KLEIN team [211] the seriousness of the burns is directly proportional to exposure time and energy output.

A 1000 W beam at penetration of 0.001 cm/s/w/cm² will produce a localized burn on the soft areas of 1 cm deep on 1 cm² according to the color (the whiter the area the deeper the burn [189].

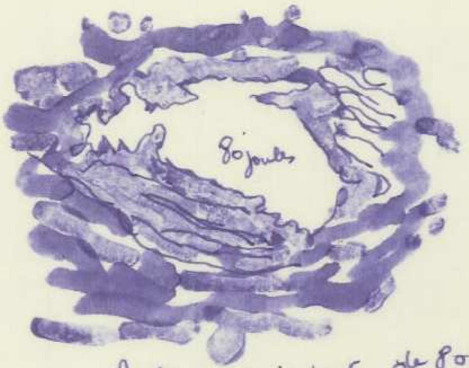
For albinos, 40% is absorbed, 20% is reflected and 40% transmitted [212]. Whitening of tattoos is not only thermal (it is followed by an edema [213]). Low-energy radiation (0.5 joules) of the forearm of a volunteer over a 9-month period provoked clinical alterations (itching, nodule) and histological changes of the epidermus, appendices and vessels [214]. Analogous studies centered on various tissues [215] for example with crystal rubies.

From the beginning the result has always been the same [216] : protection.

### III – 2 – 3 – 3 – Effect on tissues

Studies on tissues have been done in two very distinct ways (micro and macro radiation) on isolated cells or on cell systems.

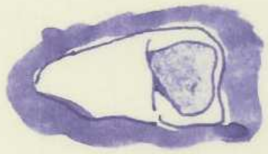
The effect of the ruby laser on isolated cells in green-colored, JANUS B cultures led to numerous effects (contrasting phase microscope) [221]. Liver cells were often studied [222] along with applications on cancerous cells. These studies conducted by FINE [223] led to observations with the electronic microscope [224]. According to FINE [225] focal necrosis of the liver can result from laser radiation through the muscles of the abdominal lining. Thermal and optical phenomena occurred during transmission with everything ending up in microscopic and histo-pathological modifications of the hepatic region. These same modifications were observed in the spleen and the kidneys [226]. With a pulsating (rubies and neodyme) and continuous ($CO_2$) radiation, lesions are essentially thermal. Here again there is a differentiation in pigmentation. There is also vaporization of tissue liquids and space formation by cellular distorsion.



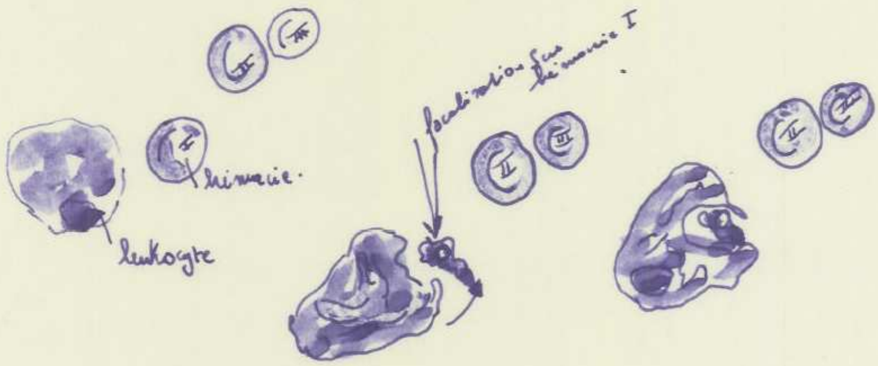


Aortes après impacts de 80 jours

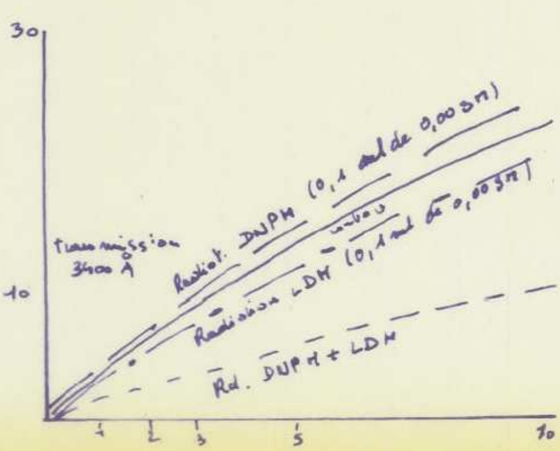
(dessin 44ab)



dent 30 jours (dessin 44c) [232]




dessin 44 d [234]




dessin 44e [238]

High energy was then used (10,000 joules) [228] and thresholds established [229]. There is a direct relation between impulsion energy and the degree of pigmentation. Tissue characteristics are not very important. Under radiation conditions there is a correlation of the liver (constant dielectric, resistance,…) and the seriousness of the hepatic attack [230]. A permanent control of the attack could therefore be immersed in any tissue. We show as an example (drawing 43 c) the rupture of a protoblasm [231] (pulse of 15 millijoules). The cells can therefore be separated. A complete series of cuts [232] was done by GOLDMAN including the section of a tooth (30 joules) through a mirror (of a ruby laser) (drawings 44 a, b and c).

Energy can be calculated [233]. A cell that has been destroyed by a laser beam is phagocyted as are all other cells [234] (drawing 44 d).

Conclusion :
In view of these observations, we come to the conclusion that the ray is absorbed by tissue cultures according to their absorption coefficient and that burns can be guided along a non absorbing part (abdomen). Destroyed cells are eliminated in the normal way.

### III – 2 – 3 – 4 – Effect on the cell

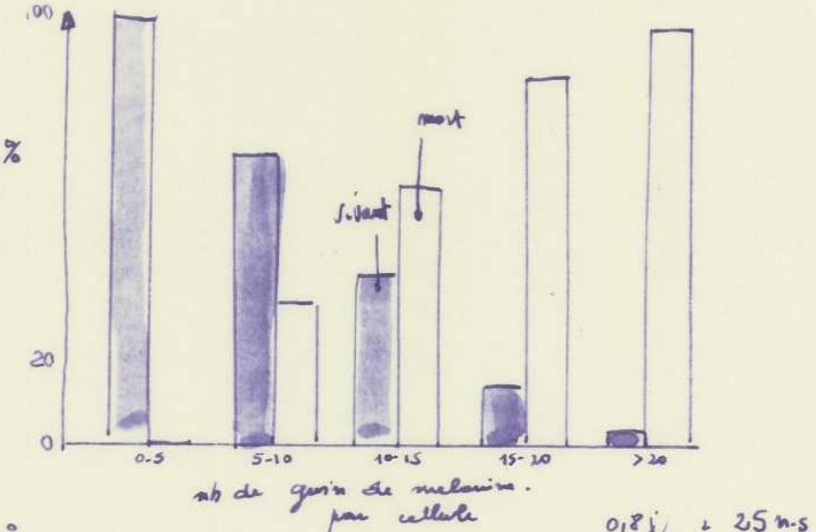
We have seen cellular explosion and water evaporation by protoplasmic dispersion [231].

The ruby laser has a destructive effect on a cell layer [235] and forms a center with a cytoplasmic area joined at a radial disposition. Two effects are verified : thermal and kinetic. Here again, the effect is tied to the green JANUS B content and localization (the thermal effect seems to be the most dangerous).

Spectre d'absorption.

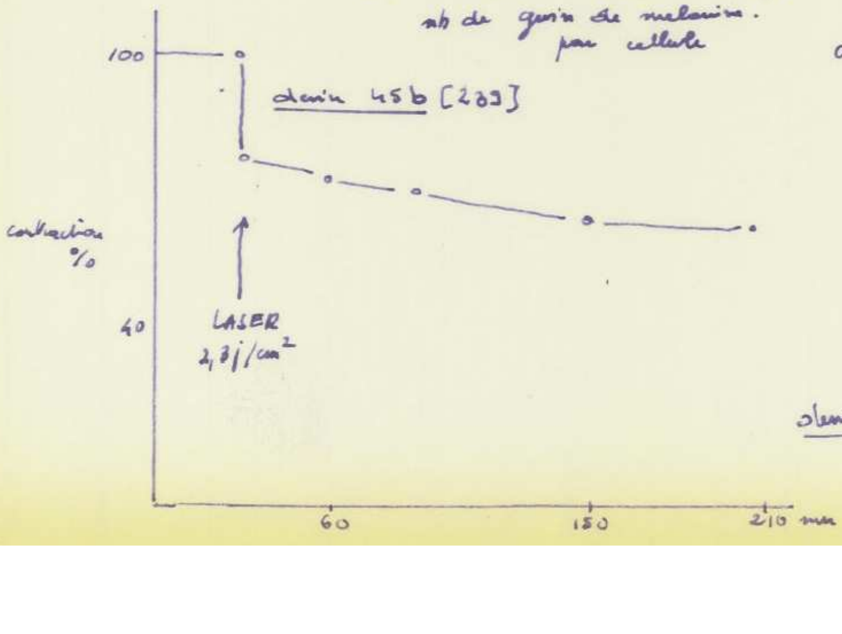
| | | | | |
|---|---|---|---|---|
| Amino acide, peptides proteines | 2,800 | | | |
| Base ; nucleotide, A. Nucleiques | 2,600 2,650 | | | |
| Vitamines | | | | |
| Phosphate pyridoxal | 2,450 (H+) | 3,880 (OH-) | | |
| Nicotinique Amide | | 3,850 | | |
| A | | 3,250 | | |
| Riboflavine | 2,660 | 3,710 | 4,140 4,750 | |
| B12 | 2,780 | 3,610 | | 5,500 |
| D | 2,645 | | | |
| E | 2,940 | | | |
| Folique | 2,550 2,860 | 3,650 | | |
| Coenzymes | | | | |
| DPNH | 2600 | 3,400 | | |
| NADH | 2,600 | 3,400 | | |
| FADH | 2,600 | 3,660 | 4,650 | |
| Cytochromes | | | | |
| a | | | 4,520 | 6,050 |
| b | | | 4,320 | 5,300, 5,610 |
| c | | | 4,080 4,150 (ox) (red) | 5,200 5,300 5,500 (ox) (red) |
| Oxidase | | | 4,400 | 6,000 |

dessin 45a [238]




0,8 j/cm² 25 n-s

dessin 45b [239]




dessin 45c [239]

Many necessary instruments are varied as micro radiation results in morphological and biochemical variations [237]. Determining the sensitivity of pigmented cells has been established [238] at around 6943 Å. In order for the rays to be harmful, a pickup substance must be present. There seems to be a variation of the biochemical potential. Each material absorbs in a very precise zone, thus leading to a reaction such as :

LACTIC DEHYDROGENATION
PYROVATE + DPNM $\rightleftharpoons$ LACTATE + DPN

This can be well-oriented in this direction: Pyruvate to lactate, according to the radiation (drawings 44 e and 45 a).

The pigment problem remains (drawing 45 b). Another action is attempted [239] on contractible cells. The ruby laser on the squeletal cardiac muscle… appears to cause deactivation of the adenosine triphosphate, visible in drawing 45 c.

### III – 2 – 3 – 5 – Effect on the nucleolus [240]

(myocardiac and endothelial cells)
Radiation 5145 and 4880 Å
Amino-acoridyne and quinocrine chloride coloration is necessary. Through the microscope with phase contrast we note lesions on the nucleolus with a halo (3 hours).

### III – 2 – 3 – 6 – Effect on mitochondria

Under the action of a ruby laser's micro beam [241] colored in JANUS green, again at 2.6 Kv, 0.5 joules, 50/1 seconds, 6943 Å, the mitochondria is transformed into a dark mass with some parts completely destroyed and others intact.

We can therefore say there was classic and selective thermal damage of the mitochondria with certain parameters. According to TANAKA [243] under certain conditions mitochondria undergoes an evolution comparable to that of mitochondria colored in JANUS B green and involution of ridges without upsetting the overall structure.

The opaque substance is of coagulated proteins.

III – 2 – 3 – 7 – Effect on chromosomes

At certain doses, the D.N.A. disappears [244]. The mitotic cycle does not seem modified at weak doses. We note that there are chromosomal aberrations in the embryonic fibroblastes in humans linked to the frequency and the 6228 Å dose [245].

III – 2 – 4 – Bacterial and viral levels

The effect of the ruby laser has been studied by DESHAUX in Lyon at PEREZ [246- 247]. The effect of laser on a solid base or in suspension is "all or nothing". If thermal phenomenum is avoided, nothing happens (no biochemical or genetic modification). This is due to the choice of wavelength in a ray released at 3 joules in 30 mono-seconds.

Upon release we note a break but constant mortality level (20 joules in 1 millisecond). In chlamydonomes we note [248] activation of the transfer of electrons in the cytochrome.

Variations of the lethal threshold of cytochromes have been studied [249].
Many studies have centered on epithelial KB leading to observe the changes in chondriome, polysome and ergastoplasm according to the level [250] : death or return to a normal status.

MALI [251] gives a description of a device which permits a target of µ1.

## III – 3 – CONCLUSION – PROTECTION

What can be said about the danger of laser rays on an organism ?
Since 1965 numerous articles have appeared regarding the danger of lasers. ZORET [252] described three cases of accidental exposure. We have seen successively the action zones (see above).

Many types of glass have been proposed [253-254] in which the wavelength was planned, especially absorbant ones at 694.3 mm until the infrared. Since 1968, general regulations with regards to incidental rays have been proposed.

The most exposed organs are the eyes and the skin. When the beam is focused, the burns it inflicts can be very serious but not extensive; with unfocused and even more powerful beams, the burns are weak. Direct or indirect rays are dangerous. In any case, for our hologram we must use a beam that is coherent, with very short impulsion, weak energy and a wavelength at 650 nm.

The zone where we will work in is far from the dangerous zone. We are not looking for power but coherence. But one thing is certain and that is once we have chosen our wavelength, we must proceed with numerous quantitative studies before confirming that interaction with the human body is safe.

## III – 4 – THE LASER IN OPERATORY DENTISTRY

### III – 4 – 1 – Effect on bones

As a foundation we note the work of HOYBERG [273]. A $410^{10}$ W/cm² laser cuts the bone at a thickness of 0.3 to 1 mm (15% to 25% of the energy crosses the cuts without causing any perforations).

Humid cuts have higher transmission than dry ones.

### III – 4 – 2 – This leads us to the effect of the laser on teeth

The way we will use the laser is very restricted regarding the teeth. What interests us are simple reflection and various absorptions by the teeth and bones. Thanks to KINESSLY [264] we know that perforations depend on the beam's energy, the type and thickness of the treated substance, the type of optical focus, the operating distance and the concentration of the added dye. It is necessary to dye the tooth. It is also possible to cut or burn (microcrater) a tooth [254]. The effect of the focused ray is above all thermal [261] which makes heat transmission from non sensitive zones to sensitive ones.

What can we say in 1973 about the laser's effects ? First there were several periods. The period of hope at the beginning when only the effects [254 to 268] were seen and not the consequences. Then more or less favorable consequences were discovered and we went through a useless phase of disinterest, no matter what GOLDMANN and MENDELSON think [266]. In 1965, STERN spoke about destruction of enamel prisms and in 1973 [260] he talks about protection of the $CO_2$ laser against acid attack.

I am not criticizing the usual experimental process but I want to point out to the readers that the laser is not a dental drill. In one year it will evolve.

There is a lot of heat absorption by the laser if the teeth are colored. This confirms KINESTLY's [264] observations. Today after all the work that has been done on burning according to enamel structure, we can speak of a "burn dose" [269]. This is a secondary effect of the laser because it is a means of protection of the dental organ, is it not ? [271 - 272].

Today research is oriented in many directions but this is not the goal of our study (cf. BULLIER – thesis [89]). For us, absorption is linked to factors whose variation can be guided in different reflection zones.

Knowing the absorption coefficients I can present two problems that can only be solved by long experimentation.

III – 4 – 3 – Our study regarding the Rx laser

If a laser ray reacts according to the environment's appearance, why could we not obtain a reflection on internal layers ? In other words, why not imagine that where a bone is volontarily colored, reflection would occur electively on the bone and the hologram would be that of the bone ?

In the same way, coloring the vessels could lead to restructuring the internal environment without having to use bleeding methods. Why not conceive an association between the Rx laser and the hologram leading, by our method, to a three-dimensional X-ray structure ?

This succession of studies is only meant to guide and to attract attention. Using current data, a study of permeability and reflection joined with a rigorous observation of the behavior of radiated environments could lead to extremely surprising applications (drawing 46).

### III – 4 – 4 – Tumors and bistoury

We want to point out briefly that the Russians [98] seem to be very advanced in the study of the laser's therapeutic effect on tumors. Also the laser lancet is an extremely interesting application. It is a tool that works according to the function of the fibers, a wonderful aid. A revolutionary fiber was perfected over several months which gives me hope for the method's future (see below). (The price of the laser is not much different from that of the electric lancet).

### III – 4 – 5 – Conclusion

The laser has several very different effects on tissues :
-thermal
-elastic
-kinetic
-electric
but these are tied to four tissue factors :
-surface state (brilliance)
-transparency (coloring)
-refraction index
-ionisation potential
-photonic conductibility

The more transparent the environment, the less it absorbs. The smoother it is, the more it reflects.

So conditions of use depends on :
-wavelength
-power
-time

<u>-Relaxed means</u>
The laser's effect appears when the number of charged atoms on the total number exceeds the stimulated emission threshold (succession).

<u>-Release means</u>
Power is pushed to the maximum and is released in an impulsion.

<u>-Continuous means</u>
Maintaining the atom charge leads to continuous action.

<u>Solutions</u>
All these factors must be treated independently then together to come to strict conclusions.

In our future studies with the hologram, energies and wavelengths can be chosen outside the danger zones. In any case, protection can always be achieved.

# THE HOLOGRAM

## Description

- DENIS GABOR AND HOLOGRAPHY
- THE PRINCIPLE OF HOLOGRAPHY
- RELIEF HOLOGRAPHY
- VARIOUS HOLOGRAMS

# CHAPTER - IV

## IV – 1 – DENIS GABOR AND HOLOGRAPHY

Holography and the laser are not the same thing. Holography dates from 1948. The laser is its striking application.
Holography is based on the undulatory nature of light (YOUNG) (drawing 47 a). As we will study later, the interference is calculated mathematically as is the energy at each point. As we demonstrated in Chapter II, to obtain interferences they must be coherent and to obtain numerous fringes, they must be as monochromatic as possible (the coherence length is the maximal difference between the trajectories that can follow two light rays coming from the same source giving observable interferences). Photography loses the phase and registers only the energy.

In holography we set fix waves on the hologram. We obtain a maximum where the two phases will be complementary and vice versa, we will obtain a minimum.

Conclusion : Problem

There is a definite effect of the laser on tissues and of various types:

- thermal
- elastic
- kinetic
- electric

- But this is tied to four tissue factors :

  - surface condition (brilliance)
  - transparency (coloration)
  - refraction index
  - ionization potential
  - photonic conductibility

The more transparent the environment, the less it absorbs, the smoother the environment, the more it reflects.

- Finally, the conditions of use depend on :

- Relaxed means: the laser's effect appears when the number of charged atoms out of the total number surpasses the stimulated emission threshold (succession).

- Released means: we inflate the power to the maximum and we release in an impulsion.

- Continuous means: the maintenance of the atomic charge leads to a continuous action.

By relighting a hologram with the same source we obtain a phase, then at the moment of the encounter with the hologram, the recreated interference restores the object. The light of the image imagined by LEITH and UPATNEIK in 1962 is called: oblique reference waves and was made possible by the great coherence length of the helium-neon laser. This idea allowed them to contour the object rather than going through it since the reference wave was separated in depth but also angularly by twice the angle of incidence. The intensity of this laser, several times higher, the slow emulsions with fine grains could be used.
A hologram must not vibrate and the impulsion must be very brief. This can be done with the impulsion laser.

**IV – 2 – THE PRINCIPLE OF HOLOGRAPHY**

Let us briefly review :

IV – 2 – 1 – Electromagnetic waves [91]

We know that in a radiated field there are maxima and minima depending on whether the wave coming from two sources is in phase or in contrast phase in the broad sense of the term.
This is a qualitative interpretation of the phenomenum.

If R is the distance to time t, the value of the field will be:

E (r) = $\frac{-93(r-r/2\sin t}{4\pi\varepsilon c^2 F}$

We have $^{(r-r/2)}$ which is the equation to time (t-r/2) or slowed acceleration.

IV – 2 – 2 – Radiation energy

We saw (in Chapter II) radiation energy's own values. The energy varies inversely according to the distance.

We affirmed that the energy was proportional to the square field. This indicates that the source's energy diminishes. As we move away, it varies as the inverse of the distance square (drawing 47 b).

If we want to retrieve the maximum energy in the wave, in a certain cone, at a distance v1, we find that at a distance v2 the quantity of energy per unit of the intercepted surface varies directly as does the v1 square. So the energy we can extract from the wave inside a certain cone is the same no matter what our distance. The total energy that we can extract from the complete wave by placing an oscillator around is a fixed given quantity. Thus the fact that the amplitude varies in $\frac{1}{v}$ means the acceptance of the existence of an energy fire which moves forward continuously displaying onto a larger and larger effective surface. So we see that after oscillation, a charge loses some of its energy which it can never recover.

IV – 2 – 3 – Sinusoidal wave

A wave oscillates at an angular frequency "w" :
It is the rate of change of phase with time (radian/second).

If we set t and observe the wave in function of v, the energy oscillates in exactly in the same way. We can define K as the rate of change with the distance.

If the phase $\Psi$ = w (r-r/2)

The rate of change

$$\frac{d\Psi}{dr} = K - \frac{W}{C}$$

IV – 2 – 4 – Two radiating dipoles [91]

What is the effect of two oscillators on a given point? If the two oscillators contribute in phase (electromagnetic wave), the electrical field is twice as strong and the intensity four times higher than if there were only one single oscillator.

IV – 2 – 5 – Mathematics of the interference [91]

Quantitative calculation
The two oscillators, in our case, have a relative intrinsic phase in relation to each other and at a given point two different intensities A1 and A2. The difference in phase is due to the difference in distance. The sum R of the two waves is :

$$R = A_1 \cos(wt + \varphi_1) + A_2 \cos(\varphi \int \Gamma + \varphi_2)$$

-Geometric means to combine the two waves
(see drawing 47 c)

The entire diagram is considered to turn in counter-clockwise at an angular frequency w.

We obtain in the calculation the effect of the interference which is in reality the difference between what we have by adding the intensities and what we effectively obtain.

IV – 2 – 6 – Diffraction [91]

Diffraction and interference are differentiated only by the fact that the first term is linked to a large number of equal oscillators.

IV – 2 – 7 – Laser and interference [77]

If we use a classic source we must sacrifice around 95% of the light radiated by the source because in YOUNG's experiment in 1820, a weak part passes through the slits.

In other words, the intensity of the fraction of coherent light that can be used with ordinary sources is always extremely weak.

The laser appears as the primary, intense source of coherent light and the alternation of bright and dark zones can be seen clearly (phases or contrasts of phase) (drawings 47 d-e).

Also, naked light does not exactly move in a straight line. Of course, FERNAT's [91] principle of least time exists, but other factors come into play. A light wave has such a short length in relation to the objects it encounters that it is imperceptibly derived considering the diffusion phenomenum.

The wave penetrating an opening spreads out at the exit (illustration of the phenomenum) (drawing 48 a).

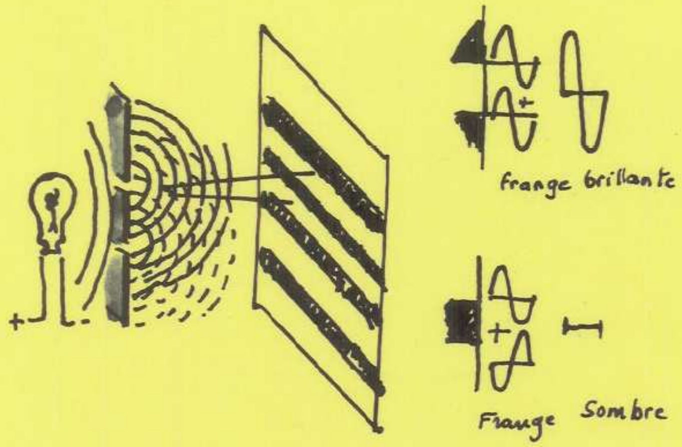
The light ray diffraction is already implied in YOUNG's experiment. The passage of light through narrow slits provokes their diffraction and spreading of one part and another. The beams will intermingle and interfere.

The diffraction combination and interference give the image in 3 dimensions (drawing 48 b).

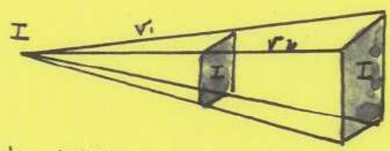
## IV – 3 – HOLOGRAPHY AND RELIEF

### IV – 3 – 1 – Theory

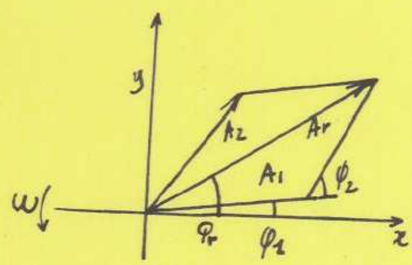
While the image with two colored glasses provokes the relief impression, the relief is reconstructed with the hologram. In other words, objects can be contoured.



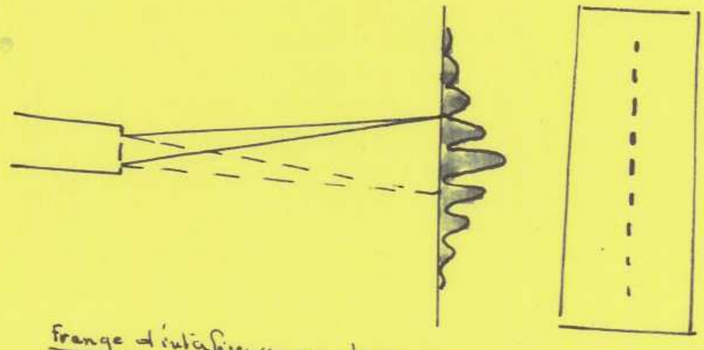

expérience de Young (dessin 47a)




dessin 47b




utilisation des cosinus
(dessin 47c)



frange d'interférence au laser [77]
Il y a superposition sur une plaque photographique

(dessin 47de)

When we take a simple photograph of an object, a light carrying information penetrates the dark room. Sensitivity is tied only to intensity (see IV – 2 – 2 and chapter II).

The notion of distance is translated only in intensity so the distance between objects and us cannot be known. We know theoretically (Chapter IV-2-3) that we can know the distance without knowing the phase: concretely, this information is deduced from the phase displacement of the waves which reach the photosensitive surface at a given moment.

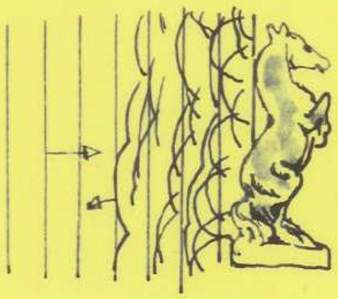
The arrival on the plate is shown by the light and dark zones, as we have seen. Let us suppose that the two wavelines are spheric (drawing 48 c). The fringes will be circular and their width decreases as they move away from the center. The difference between the network formed on the plate in the two cases is characteristic of the nature of the second beam used. If we consider the first waveline as a reference beam (perpendicular to the plate), the plate's network contains the information required to restore the second waveline which is the signal beam. This is the principle of holography.

In order to obtain this reflection, LEIT and UPAITNIECKS created the image of a locomotive, a toy of 50 cm in length, with the help of a laser with rays of 5 W power. The gas laser is the best [98] because it is more monochromatic; this system does not require a lens or objective. The laser beam directed toward an optical system that forms it is enlarged without disturbing the coherence. The field must be of a sufficient size to cover the object to be photographed (for us, 7 cm by 7 for a complete impression, or 1 cm by 2 for a tooth).

This beam is then directed toward the object by the so-called direct ray with one part striking the mirror (reference ray). Both rays, one returned by the object and the other direct, interfere with the plate.

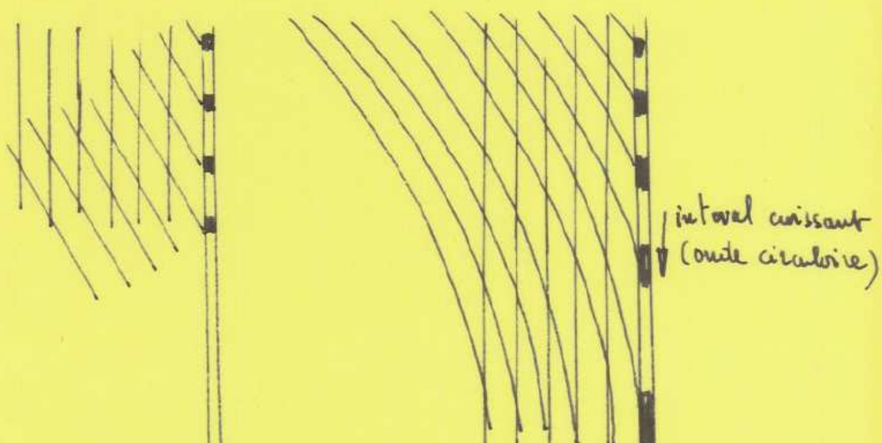
diffraction. l'étalement est moindre si la λ diminue

(dessin 48a)



diffusion : d'un objet simple.
d'un objet complexe (ensemble de très nombreux points unités)

(dessin 48b)




Retranchement des amplitudes de 2 trains d'ondes

(dessin 48c)

As we know, the waves of the reference ray are equal in amplitude and length and are characterized by the same relation in phase. The echo waves have different amplitudes and aleatory phases. All the series of spherical waves whose appearance corresponds, for each of them to a certain point of the surface of the object which reflects is an extremely complex process.
The interference fringes recorded by the hologram have a ray density which depends upon the size of the angle formed by the direction of the waves propagation carrying the information about the object and the direction of reference waves propagation (drawing 49 a and b).

IV – 3 – 2 – The hologram

Our plate does not show an object but a group of interferences which, in coded form, represent the information of the signal beam. In addition to presenting the intensity, it presents the phase displacement.

The following calculations indicate the steps to take for the recording and restoring the information.

A three-dimensional object lit by a coherent wave

$\varepsilon$ is the diffracted wave.
$\varepsilon_r$ is the reference wave.

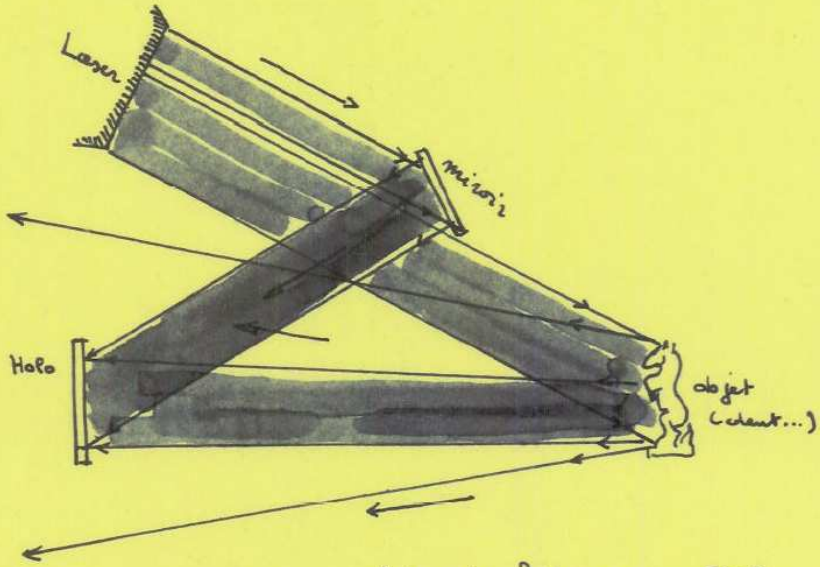
If we disregard the time factor

The total intensity that falls on the photographic emulsion at the time of recording is equal to the sum squared of the amplitudes of the two waves which superpose themselves one upon the other [276 – 277 - 278].

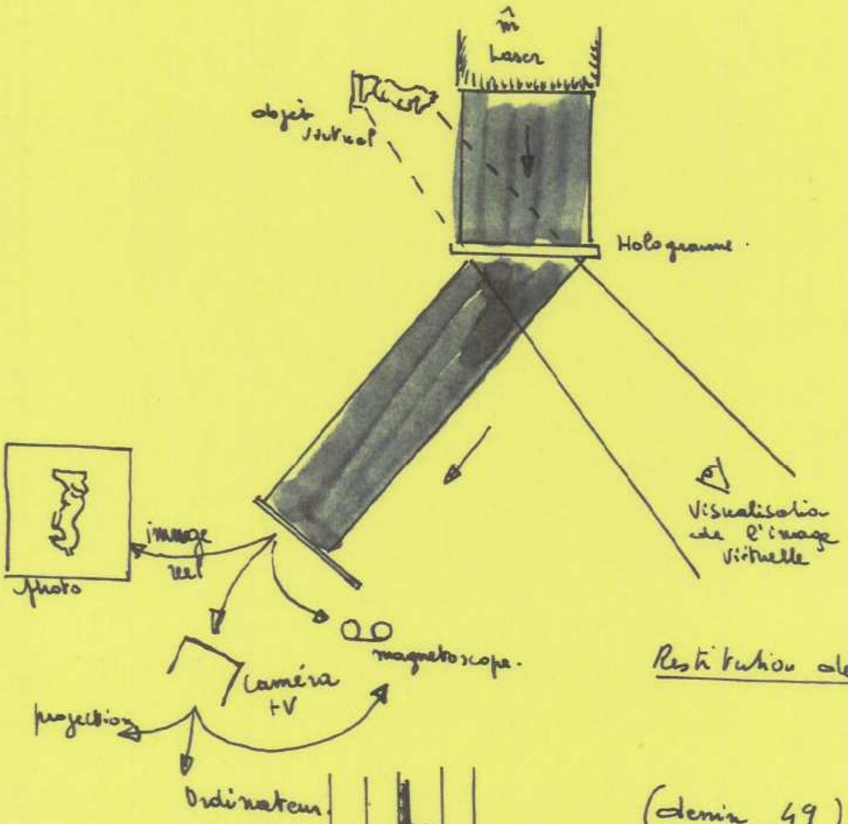
$I = (\varepsilon + \varepsilon_r)^2$

$I = A^2 (x, y) + A_r^2 + A (x, y) \exp J \varphi A_r^* \exp\text{-}J\varphi + A^*$
$(xy) \exp -J\varphi^r A_{rc} \exp J\varphi\ r$

where $I = A (x, y) + A_r^2 - 2A (x, y) - A_r (\cos [\varphi (x, y) - \varphi_0 ]$



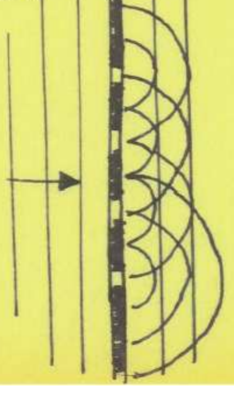

prise de hologramme. [77]




Restitution de hologramme.

[77 modifié]

(dessin 49)



principe de Restitution

We note that in the third term, the displacement of object y (x,y) is present.

X ($\mu$) = F (E-t)

We can thus calculate the transparency to amplitude t (a) of the hologram. If we make it intervene, the contrast factor of the emulsion t (a) is proportional to F $\gamma/2$..

If we work in the linear region of the curve where E t represents the product of light by the exposure time, this transparency will be considered proportional to the energy received from the hologram.

For Denis YUNK [280 - 281], the proof that the three dimensions are reduced to two dimensions should be considered since the hologram is a system equivalent to the object.
This is difficult to prove because no method of predetermination in the arbitrary "three-dimensional object" is known in optics. The liaison parameter proposed by Denis YUNK is a three-dimensional function of the dielectrical constant of distribution.

The dielectrical constant would be in "convolutions" with the function [F ($\vec{R_0} - \vec{R}$)] the result of specific waves of the object and this incidence (see drawing for transition 3, dimensions in 2 on a hologram).

For MALLIEK and ROLLIN [282] information from each point of the object is not dispersed everywhere on the hologram's surface but on a very small surface. Also, a hologram could be considered as being a high number micro-hologram representing a region of the object.

Mario BERTOLOTTI of the University of Rome proposes a method for measuring amplitude and phase variations at any point of the wave's front side of the wave. Therefore, the technique is at the same level as the theory [283] in the field of holography.

IV – 3 – 3 – Reconstruction

How can we decode such a complex image? Nothing could be easier. All we need to do is cross it with a laser oriented in the same direction as the beam used for making the hologram.

Reconstruction is due to the diffraction phenomenum. When the hologram is lit, for example by an identical wave to a reference wave, the result is expressed in a quantity that is proportional to the product of t a (or again I) by the wave's function, so that :

(drawing 50) $t_a \quad A_r$ exp J $\rho$.

With the reconstruction of one part or another of the direct light beam, two images with an almost multiplicative factor appear paired with the object and following symmetrical directions in relation to those of the reconstruction beam.

- Plate

An observer placed on the other side will see objects through the hologram and if he literally moves his head he will see the effect of the parallax characteristic of real three-dimensional images.

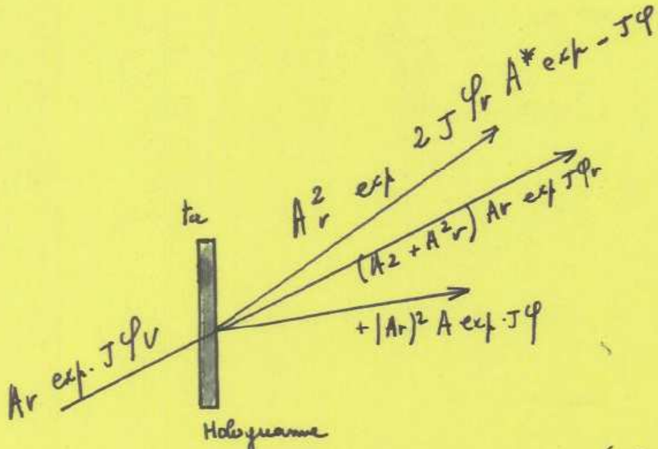
Why ? Because the phenomenum explained above indicates that the dark fringes stop $\varepsilon_r$ and the light fringes let is pass through. Then there are diffraction and interference. The hologram is a "fixed" wave going everywhere then set on course.

- Television

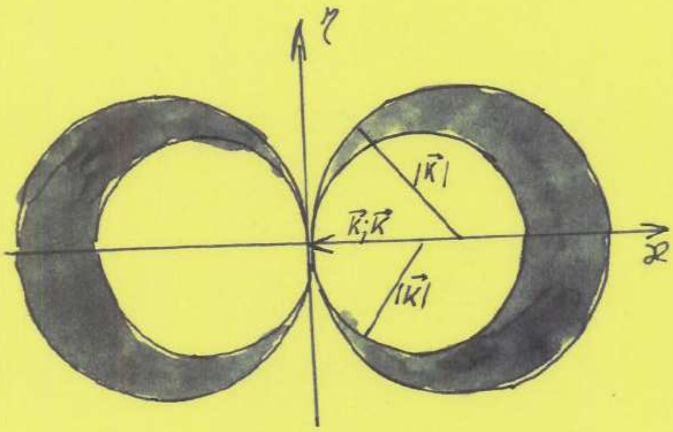
We have presented ourselves with a problem: quickly do a direct analysis of the volume (holographic camera) or analyze it indirectly by analyzing the hologram.

We chose an average term which is:

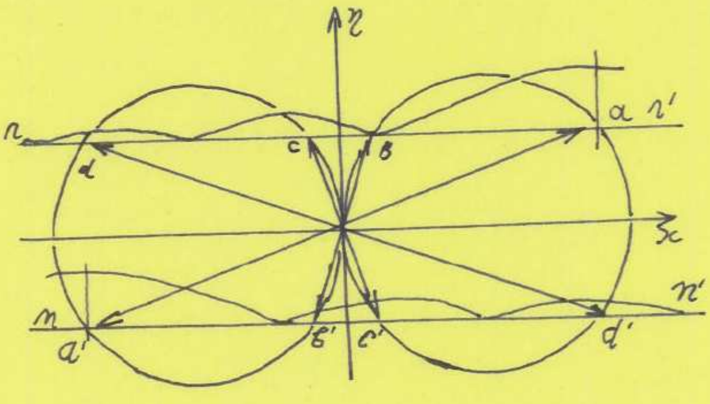
Shoot the hologram on a high definition (classical) gel (sensitive) then do an analysis of the hologram with precision in various positions to effectively sculpt in three dimensions.




(dessin 50 a)




Représentation d'un objet en onde plane




transition d'un objet 3 dimensions en 2 dimensions

les deux schémas de bases de Denisyuk

(dessin 50b)

We do not take television directly to do a more complete analysis of the three dimensions.
Before analyzing the study methods of the hologram, we will explain how it is made.

## **IV – 4 – DIFFERENT HOLOGRAMS** [277 – 278 - 279]

### IV – 4 – 1 – Hologram by transmission

Waves $\varepsilon$ and $\varepsilon_r$ superposed in the hologram's plane emanate from a transparent object after crossing it which can be a thin, pierced piece.

A wave is thus separated into two parts. The only problem is not to have the two paths surpass the length of coherence.

### IV – 4 – 2 – Hologram by reflection

Wave $\varepsilon_{1-2}$ is obtained by diffusion and diffraction of the light. Objects (1) and (2) displayed in front of the photographic plate P are lit by a spherical wave S.

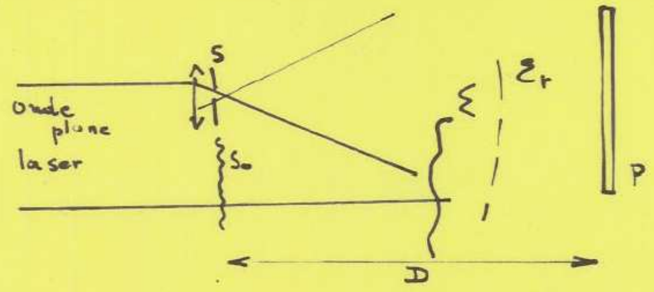
At the level of P, waves $\varepsilon_r$ and $\varepsilon_{1-2}$ superpose themselves on one another and interfere. The difference in the optical path between two points A and B are translated by a phase displacement of wave $\varepsilon_{1-2}$ recorded in the hologram's memory. During restitution both images will appear one behind the other (drawing 52).

### IV – 4 – 3 – Frequency-bearing hologram

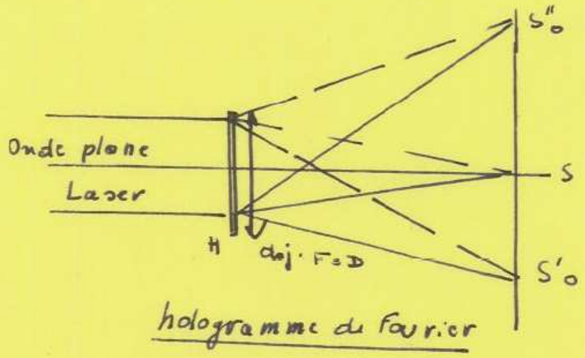
The transmitted wave is recorded and the wave is diffracted (not interesting for us because non transparent).

Conclusion :
To set the image in three dimensions, we must have recourse to the hologram, in other words, to optical interferences. This also allows us to find many solutions to certain problems.

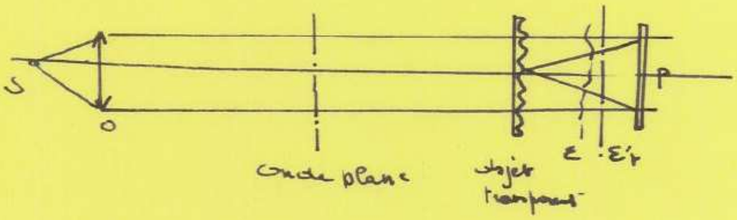
Différents montage pour hologramme.
(dessin 5? et 54)

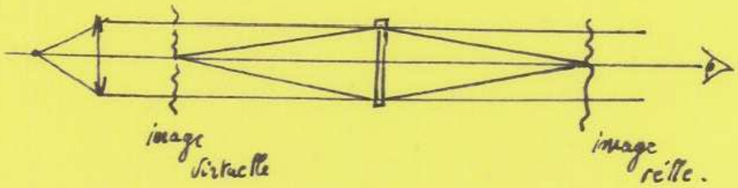



objet transparent

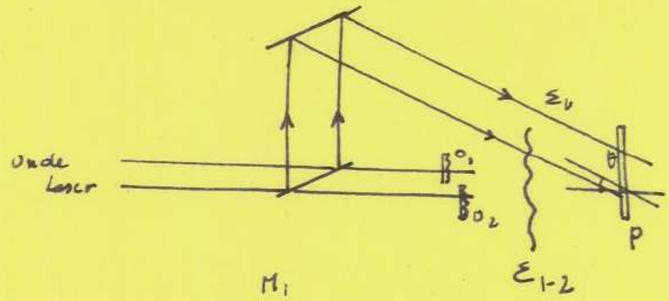


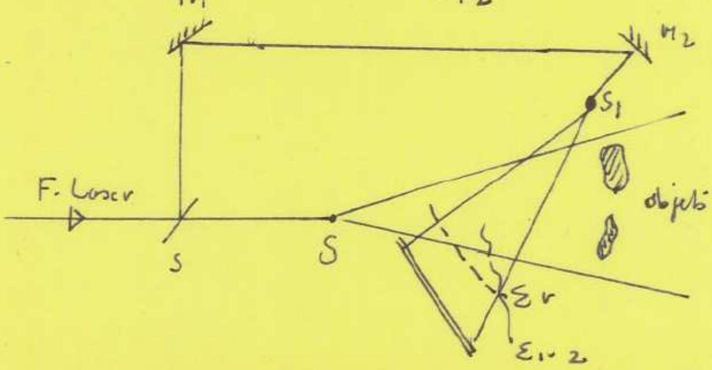

hologramme de Fourier




hologramme de Gabor



# ANALYTIC CONVERTER

## Description

- TRANSMISSION OF HOLOGRAPHIC-TYPE INFORMATION
- TRANSDUCTION OF LIGHT CURRENT
- SUMMARY
- ANALOGICAL NUMERICAL CONVERTER

# CHAPTER – V –

## V – 1 – TRANSMISSION OF HOLOGRAPHIC-TYPE INFORMATION

We already know how to store detailed information about an object, plane or three-dimensional object on a photo emulsion (on soft film or plate, etc…)

### V – 1 – 1 – Direct optical study of the impression

We choose a capturing device that will transform the light information into electrical information. These will be either projected for direct reading or used in our chain. The first phase: direct projection.

In order to be able to control the good condition of a cut, a view of the tooth is projected on a screen. A good method to rectify the problem of movement multiplication and shaking is to freeze the impression into a hologram then, in two dimensions, study the tooth by projection. The reading is done by a classical system on a hologram thus avoiding the patient's vibrations and allowing us a perfect analysis of our tooth 10 m by 10.

Once the observation is done, the sculpting process can be started. This can be done according to the size of the hologram because we know that no lens grows in three dimensions but only in two. We will propose an idea for conception in other writings.

### V – 1 – 2 – The image: its characteristics

Before defining the characteristics, let us recall what the television is [285 – 286 - 288]. The TV idea dates from 1881. What interests us primarily is achromatic TV.

V – 1 – 2 – 1 – Achromatic television

This involves decomposing the image that we want to transmit into as many elementary points as possible (minimal zone) and measuring the brilliance of each of these points. During retransmission each elementary point will be reset in a similar place on the analysis screen. Professional 35 mm cinema has a definition of 1 million elementary points.

It will therefore be very difficult for us to simultaneously transmit all these elements. Researchers have proposed a sequential analysis of the image and a sequential restoration.

Each image is explored following successive horizontal lines (drawing n° 53 a) from top to bottom, either directly or by interlaced scanning (drawing n° 53 b). The minimal dimensions of these successive points are obviously determined by the type of analysis used, the electronic brush, the spotlight. Synchronization tones at each line and these screen ends allow a well-synchronized analysis and restoration (drawing n° 53 c).

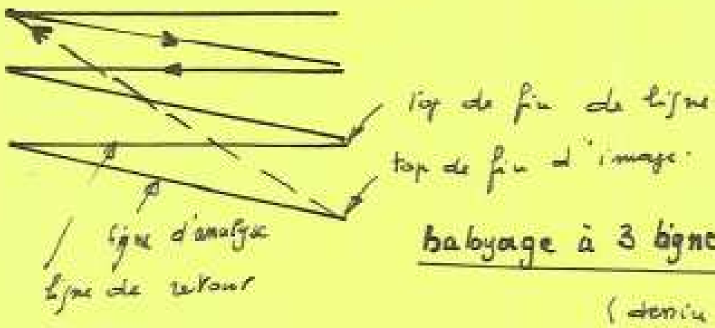
V – 1 – 2 – 2 – Electron gun and analyser tube

Thanks to ZWORYKIN's ionoscope, modified by ROSINY, we can scan the image to be analyzed using a beam of electrons. The source is a cathode. The beam which diverges quickly (even sprung up from the electrons) is gathered by an electronic lens by concentration and (or) electromagnetically. The deliberate deviation of the beam is essentially done electromagnetically (drawing n° 53 d).

In our experimentation we will use instead the laser ray which has the advantage to be thiner.

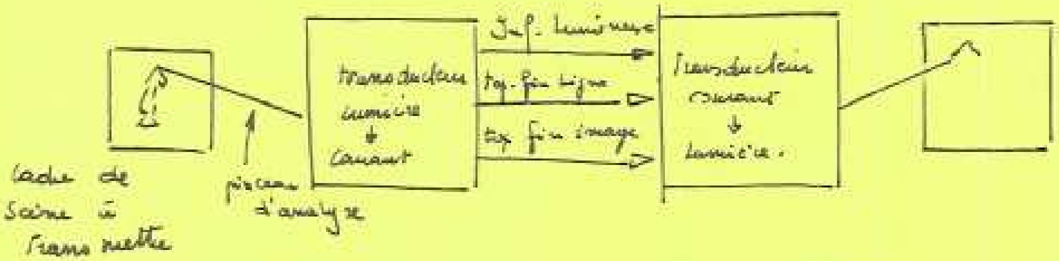
V – 1 – 2 – 3 – Transmission used

a) In real time : the transmission corresponds to a capturing device which transmits the elective signal relative to the object in such a way that at the same time the wave is directly diffracted starting from a distribution of amplitude and phase tied to the transmitted signal. There is a risk of deformation and displacement.



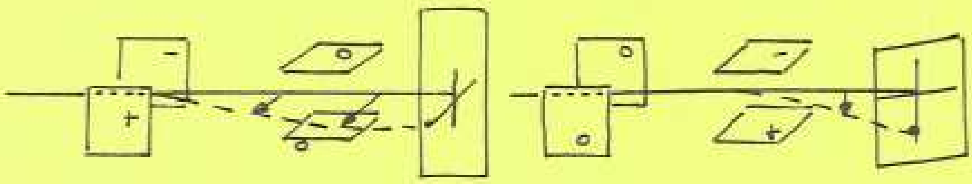

**balayage à 3 ligne**

(dessin 53a)



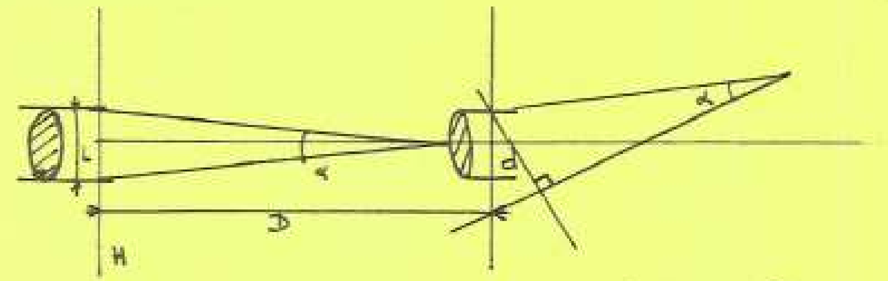

principe.

(dessin 53b)



deviation electronique

(dessin 53c)




(dessin 53d)

b) In delayed time : there is an intermediary step then creation of the hologram followed by a re-analysis of this hologram.

I mean by "delayed time", reduced, analysis by two-dimensional projection. Delayed time satisfies our own use.

V – 1 – 2 – 4 – System requirements

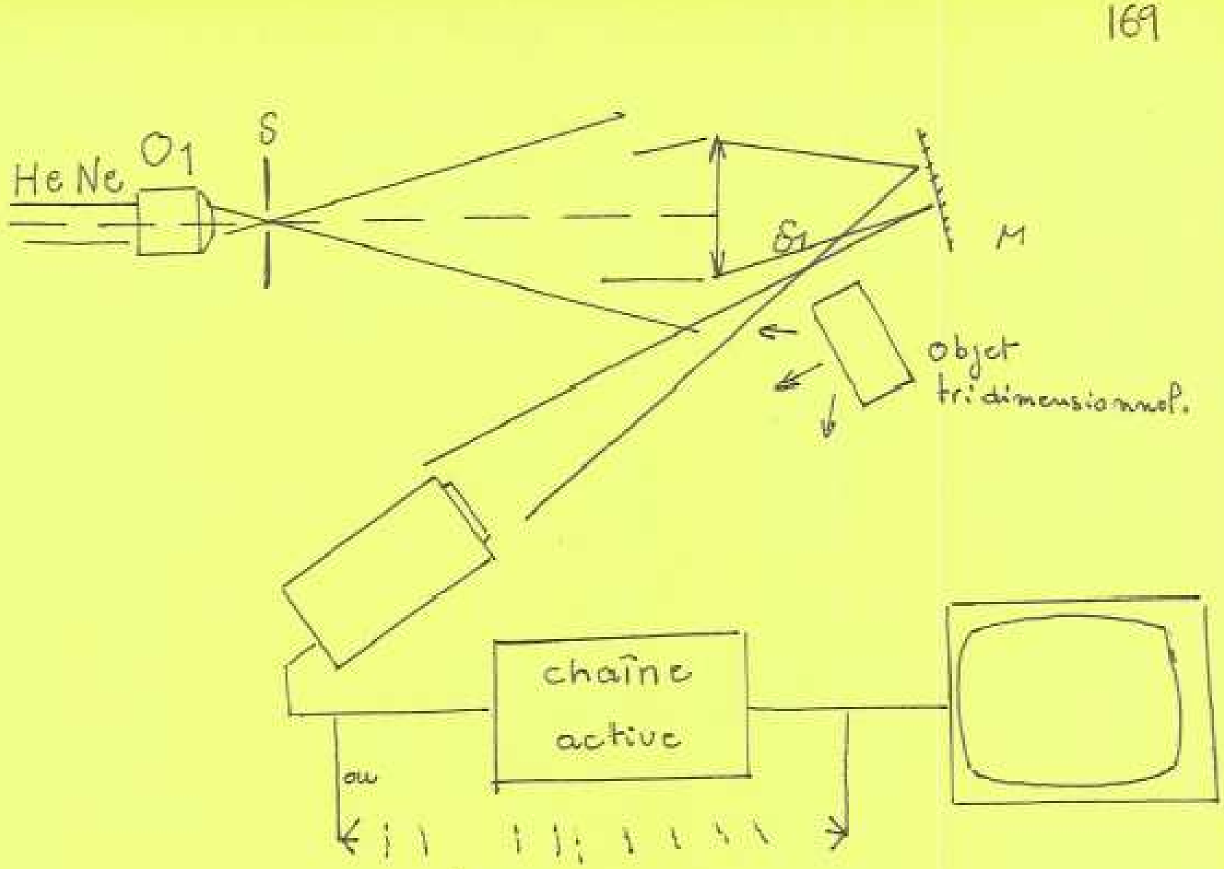
A characteristic of the three-dimensional object hologram is the considerable quantity of information it contains [289]. On a 9 x 12 cm plate we arrive at a figure of $10^{10}$ bits put in memory ($2410^4$ horizontal element) and ($1810^4$ vertical element).

We note that photographic emulsions (Kodak 649 F. AGFA 8F.50) reach 2500 to 3000 $mm^{-1}$ resolution (previous example 1000 $mm^{-1}$). To increase precision we can increase the number of lines to 20,000 or even 40,000 in space, in other words, $510^{-3}$ mm (5 μ) per line. This does not upset our precision. Let us not forget that the succession of 1/25th second does not interest us. Scanning time can be very slow.

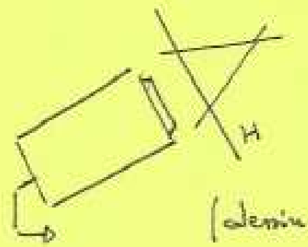
The definition of our image depends on the angle, the beams $\varepsilon_1$ and $\varepsilon_r$ and the dimensions of the object.
The object is three-dimensional. In plane P, the spatial frequency is √ = 1/i and the smallest interfringe i = $\frac{\lambda D}{d}$ and $\alpha = \frac{L}{D}$ thus √ = $\frac{\alpha D}{\lambda L}$

The spatial frequency of the fringes v depends both of the angle $\alpha$ (drawing n° 54 a) and the object (-1). However the limit value is fixed by the apparatus' technology; a compromise has to be found between the values of d and $\alpha$ or even between the values of d and D.
Practically, we choose our object, the chosen value of D is fixed by the importance of the flow on L (two flows : reference and reflected).

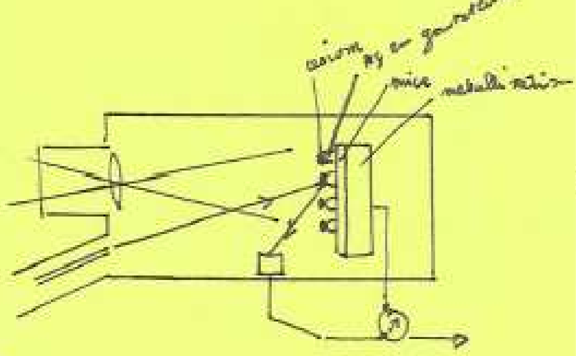
To reduce the tape width, frequencies are recorded without losing the phase displacement of the restored waves. Various methods have been proposed [290] by the SFER.



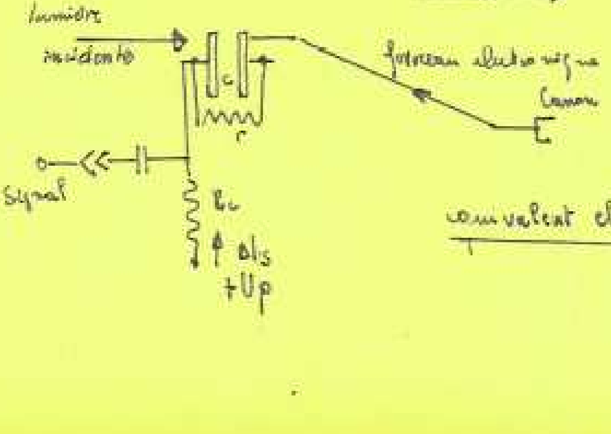

(dessin 54 a)




(dessin 54 b)




* schéma de l'iconoscope de Zworykin




(dessin 54 c)

équivalent électrique.

The KLYSTRON even reduces the tape width in relation to the laser (by a factor of 50.000 in He Ne 6328 Å).

V – 1 – 2 – 5 – Light level on the photocathode

The fringe frequency is linked to D which is itself tied to a flux which diminishes considerably with D ($\frac{1}{D^2}$). Sometimes this flux is insufficient and a light amplification can be added. It increases the size of the useable surface and the sensitivity in the area of use.

V – 1 – 3 – Transmission of the object hologram diffusing in three dimensions

We will create a practical example.

V – 1 – 3 – 1 – Transmission from the object hologram

The object is lit by a helium neon laser (coherent spherical waves 6328 Å) with variable power (10 m W ex.). One part of the wave is focused by an angle ($O_2$). A classical hologram is formed in plane H where we have placed a television camera for the transmission.
We transmit using an analyser type (see drawing n° 52).

V – 1 – 3 – 2 – Transmission from a previously created hologram

The experiments described up to now were specially done in real time.
Another method, ours is to transmit a hologram's information previously stored on a photographic emulsion.

The hologram is created. We will not extend our study any further on this technique [291].

The hologram is lit through a diffuser by a coherent or non-coherent light source. Its image is formed with the help of an optic on the window of the camera's tube.
This process requires another person, good material and represents many advantages.

1°/ - A change of scale in the hologram can be done with the help of the optic used; for example, a hologram with a maximal resolution of 40 $mm^{-1}$ can be enlarged twice in order to transmit only one part.

2°/ - The lighting level can be adapted to the sensitivity of the layer of the detector. A better resolution will thus be gained.

3°/ - The wavelength is chosen according to the spectral response of the photosensitive layer. The quantum tension is thus improved.

4°/ - Parasites (incoherent phenomena) can be diminished.

5°/ - Lighting adaptation can be done according to the darkening of the hologram.

## V – 2 – TRANSDUCTION – LIGHT – CURRENT

Analyzer tube
At the beginning of the chain is an essential organ which is the analyzer tube. Its goal is to transform the optical image placed in its field into an electrical image from which we will obtain electrical signals that we can manipulate, amplify and use to modulate a carrier wave, for example.

### V – 2 – 1 – Photoelectrical effect

It was discovered by BECQUEREL in 1839. Today we no longer resort to the voltaic effect but to the photo-emissive or photoconductor effect. We choose the material which has the highest emissive power according to the wavelength used (6396 Å for us).

COREY's system was to use an infinite number of photoelectrical cells. It is easier to use an electron analyzer tube ….

We use a cable made up of dielectrical material (drawing n° 54) and on mica. A thin layer of cesium is applied to fine silver droplets which are vaporized. Each droplet is compared to a tiny photoelectrical cathode.

If the same is sent to the analyzer, each elementary droplet of this mosaic will emit a lesser or greater number of electrons according to the lighting of the image's spot to which it corresponds. The material transforms the droplets into micro-condensers which are charged more or less. An electronic beam will analyze each droplet while discharging. This is the video signal.

The higher the collected energy, the more positive the charge of the condenser.

So to return to a zero charge, the electron beam that it will encounter will be more or less absorbed and this absorption will correspond to a variation in tension between the support plate of droplets and the reflected beam (thus between the collecting anode).
(See drawing n° 54): drawing of ZWORYKIN's ionoscope tube.

This variation in tension is the video signal frequency. The same principles are drawn from improving principles: ionoscope, image and photicon.

### V – 2 – 2 – FARRSWORTH's dissector tube

There is no electronic box. A photo-emissive material is placed behind the focus and the exiting electrons are amplified.
The advantage is that side effects are suppressed but strong lighting is necessary.

### V – 2 – 3 – Orthicon (slow analysis)

Electrons are slowed down at the moment of impact on the target. Here the video signal is made up of successive discharge currents at the beam passage, positive potential formed at the various points on the droplets (mosaic) under the effect of the incidental light.

The orthicon image tube avoids the defect of other tubes and of those of the orthicon tube. The beam electrons which have not been captured by the target and which returned to the last acceleration anode, will be used. The sensitivity of such a system is remarkable (even $10^{-3}$ lux).

V – 2 – 4 – Vidicon photoconductor and plumbicon effect

We use photo-conductibility but not photo-emission power. It exists in the form of a glass cylinder with an optical glass extremity carrying the photo-conducting target.

At the other end is the electron gun whose beam is localized and deviated by coils placed around the Vidicon body. The signal place is carried to a positive potential (10 to 30 v) in relation to the gun's cathode.

"The optical image is focalized on a photo-conducting layer. The conductivity of each point of the latter varies with the light intensity received.
Positive charges applied to the signal plate diffuse more or less rapidly through the layer so that on the rear side of the target we obtain a positive charge stereoscopy constituting a faithful electrical reflect from the projected optical image.
During the passage of the analyzer beam, each point of the target will capture the quantity of electrons needed to return its potential to that of the gun's cathode. Excess electrons are pushed back and captured by a recovery grid. Various currents corresponding to inputs of beam's electrons which cancel the target's positive charges, cross the resistance charge placed in the signal plate's circuit and create variations in potential at the edges, or video signal".

A great interest is its use as a memory tube because it can keep its information, printed on the target, for a long time.

The plubicon (lead basis) is at the achievement of fineness and precision. We have a layer of 10 to 20 μ with little points of 0.1 to 1 μ on top which obviously ensures excellent definition and allows its use to be extended to infrared.

## V – 3 – SUMMARY

From an image we obtain a tension. This image (hologram) is characterized by a considerable amount of information $10^{10}$ by 10 cm². Therefore, the number of analysis lines should result in maximum precision. To analyze $10^{10}$ units for 10 $cm^3$, we must have a scanning of at least 20,000 lines in other words, 10 μ of precision for 10 cm².
This is huge and very precise.

This is feasible if we consider that the 1/25 scanning does not interest us. Therefore, precision at this level is 5 to 10 μ on the impression made.

## V – 4 – ANALOGICAL NUMERICAL CONVERTER

### V – 4 – 1 – Electrical signal converter

One could short circuit this converter and work in tension, in other words, keep the electrical value in order to power our machine tool. This has a great inconvenience of considerably reducing our field of application. Also transmission of information to a computer and to several minor analyzers lets us exclude the price of the group's computer.

The number of significant figures read from the tension corresponds to the precision. Therefore our goal will be to reach a tension variation corresponding to a distance d = 5. This currently seems difficult (I emphasize "currently"). Given that certain analyzer tubes achieve $10^{-5}$ lux, there is hope.

We know that numerical expansion can be formulated according to various numeration systems. The decimal system is the one we use. For technical reasons, machines use the binary system for internal treatments and the binary coded decimal (BCD) for communications with humans.

963 = ◦ 1111 ◦◦ ◦◦ $^{11}$ (binary)

1 ◦◦ $^{1}$ ◦ $^{11}$ ◦◦◦ $^{11}$ (BCD )

V – 4 – 2 – Methods used (drawing n° 54)

V – 4 – 2 – 1 – Successive scanning methods

At instant zero, the visualizer V is set on zero. A generator G developing an increasing linear tension with time is started. An oscillator ch begins to send regularly spaced impulses in a totalizer T. The amplitude of the entry signal SE is composed with the increasing amplitude emitted by the generator G. As long as it is superior, everything continues. At the very moment when the increasing tension becomes equal to SE, the comparator C emits an impulse which freezes the sending of the impulsion in T. The number of stored impulses is then read which gives the growth time of the scanning tension from which we deduce the unknown amplitude.

The totalizer is, in fact, a continuation of bistables that have taken positions according to the number stored; by exploring these bistables, we obtain the numerical representation of the unknown tension.

V – 4 – 2 – 2 – Integration method (drawing n° 54)

V – 4 – 2 – 2 – 1 – Conversion, tension, frequency:

An amplifier with a As threshold forms the power of a relay Rs when the tension Vc applied to its entry reaches a certain value. Let us now consider the entry signal SE which through an amplifier AE charges a condenser C through a resistance R; we know that when a continuous tension is applied to the edges of such a circuit RC, the tension on the edges of the condenser increases exponentially with time and even more rapidly the higher the tension applied.

The higher the Se, the more rapidly tension Vc will reach the release threshold of As, at this moment the relay closes up and discharges the condenser, forcing the cycle to repeat itself. The frequency of repetition is proportional to the unknown tension; it is measured using a frequency meter totalizer open for 1 second.

### V – 4 – 2 – 2 – 2 – Double ramp method

The principle is identical except when during discharge the condenser is linked to an inverse tension of the opposite polarity. We demonstrate that this assembling allows to compensate the derivatives of diverse elements of the device and thus offers improved precision.

### V – 4 – 2 – 3 – Successive approximation method

A bistable numeric register uses interrupters to control a resistance network which delivers a tension Vi proportional to the code listed in the register. A precise compensator compares this tension Vi to the analogical signal to be converted E.

Each row of codes is tested successively beginning, for example, with the heavy weight.
If Vi > E we write 0 and go on to the next row. If Vi ≤ E we write 1 then we deduct the reference tension from the entry tension before going on to the next cycle.

This process allows us to generate successively all the bits of the representative number of the entry signal in the chosen code.

### V – 4 – 3 – Conclusion of chapters IV and V

In chapter IV, we demonstrated that the only means of taking an object in three dimensions on a two-dimensional plate is to use interference, diffusion and diffraction. We demonstrated how Denis GABOR's discovery with the hologram allows us to freeze these 3 dimensions in 2 and we gave a source of mathematical demonstration of the fact (DENIS YUK). Thus we explained the interest of the laser in GABOR's invention and what the various possibilities are. We proposed a new hologram that we will study.

So to freeze our impression in 2 dimensions while gaining much time and without the inconvenience of the micro-palpitator we will use the hologram (deferred time) or the television camera (real time).

Now we must explain how we study and especially how we restore distances with the interferences contained in the holographic piece.

"The photographic plate constituting a hologram carries only darkening variations and there is no reason why they cannot be reproduced artificially. Thanks to the computer, the amplitude emitted by a fictive object in any plane can be calculated. An auxiliary amplitude is added to it which plays the role of the amplitude produced by the coherent wave. The computer calculates the resulting intensity. A printer linked to the computer reproduces these variations in intensity on a sheet of paper. All that remains to be done is to take a photograph suitably reduced to obtain a true hologram. Objects which do not have a real existence can thus be restored in three dimensions." [297].

In chapter V, we obtained a precise tension at 5 of the separation (X Y) for a scanning of 20,000 lines on 10 $cm^2$. The goal is to have a definition of lighting allowing us to separate a depth of 5 $\mu$ ($d - d' = 5\ \mu$). This tension is thus translated into a binary system by a double-type converter, for example a quick ramp. In fact, to avoid delaying the reading process, it would be good if reading the elementary unit of the surface does not exceed 1 $10^{-5}$ seconds which seems fast! This would allow an analysis in a few minutes to the nearest 5 $\mu$.

The analysis of our image can be compared with a succession of lines that would cut the object 20,000 times. Each number or bits will be (of the tension) the distance from a considered point of the object to the hologram. This information will be analyzed and transformed by the computer.

# COMPUTER

- COMPUTER PERIPHERALS
- SOFTWARE
- COMPUTER

# CHAPTER – VI –

Information linked to scanning of the impression and transcribed in coded form will be sent by terminals (for example) to the computer for security of constants. One could easily assume a simple use in the form of electrical tension, in other words, in V form before the converter and manipulate this information to make the machine work without a numeric analogical converter. But since there is a great number of modifications to do, the risks of precision would be very annoying out of 15 or 20 successive manipulations. This would certainly increase the imprecision of intensity $\Delta V$. However, by immediately converting them into a numeric form, the error $\Delta V$ will only occur once. The only inconvenience is that the price can fluctuate considerably.

## VI – 1 - PERIPHERALS

If we compare the computer to a brain, the peripherals are the peripheral sensor-motor organs.

### VI – 1 – 1 – Canals

Tying the central unit of the computer to the peripherals, they can be selector canals (much information but linked to a single peripheral) and multiplex canals (small information to be guided such as a board, tape and this in function with the time $10^{-6}$s (information). A direct access canal lets one tie this information stored on a disk or drum bypassing the central unit (see drawing 55 a). The role of the control unit on a canal tied to a peripheral is to synchronize the input and output operations, carrying on with the treatment (check code, decodes, commands peripheral information). We note that the canal has several control units to “command”.

VI – 1 – 2 – Peripherals

VI – 1 – 2 – 1 – Slow or fast type

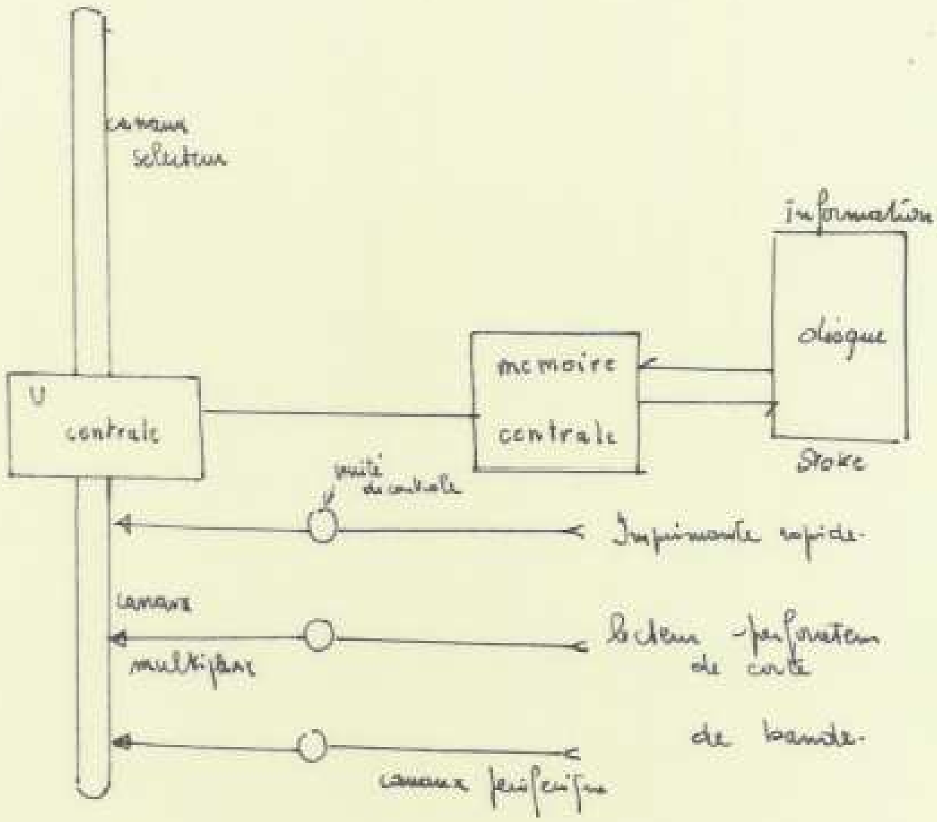
Within the slow types, we note the boards (by scanning or photoelectric cell) on 80 columns and can scan at 1000/mm, for example.

The board perforators are information receptors and receive information from the central unit. Verification of perforations is done instantly (see drawing 55 b).

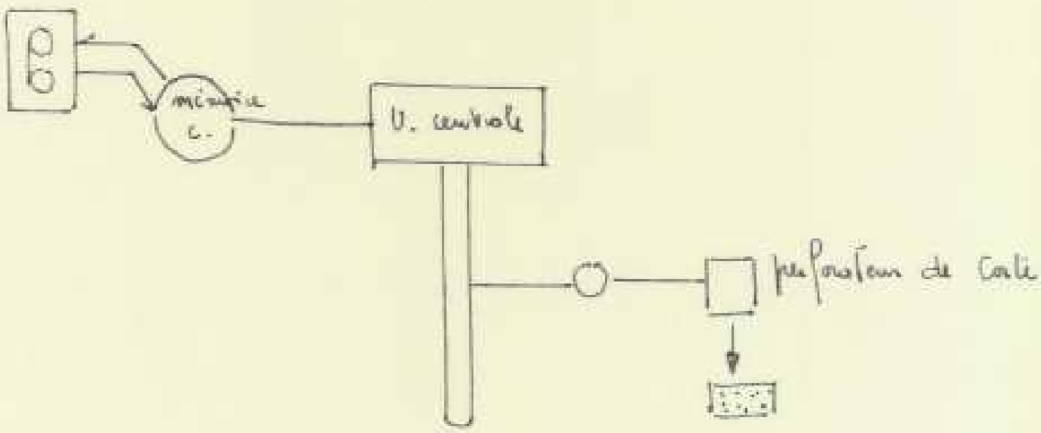
Perforated ribbons are based on the same principle (6 to 8 perforations on a width of 3 cm).
Printers are machines which receive information which allow transcription onto paper of the results of treatment processed by the central unit (see drawing n° 56 a).

VI – 1 – 2 – 2 – Quick perforators (magnetic tape, disk or drum) allow storage of information which is not constantly used (files and programs). Magnetic tape rewinders read and record the tapes.

As with a perforated tape, recorded informations are read on longitudinal bands: two types, 7 or 9 tracks (7 or 9 magnetic moments). There are two recording methods: NRZI and phase modulation. In the first one, the flow inversion is translated by a bit 1 and absence by a bit 0. In the second method, bits 1 and 0 are recorded by flow inversion. This gives 1900 to 6000 bits per inch therefore per second. The amount of information transfer would be 30,000 to 640,000 characters per second. The disk allows more rapid scanning than the magnetic tape. The drum is also very interesting.
We note that we call the compatible peripherals, “plug to plug”, in other words, peripherals sold at a low price which function on any unit (see drawing n° 56 b).




Ordinateur (dessin 55a)




périphérique ordinateur (dessin 55b)

**I**

## V – 2 – SOFTWARE

These are the computer’s programs.

## VI – 3 – COMPUTER

It is simply the principal tool. It is a machine capable to receive information in a coded form for its application and some transformations defined by a program. It gives results in a coded form.

### VI – 3 – 1 – Presentation of information

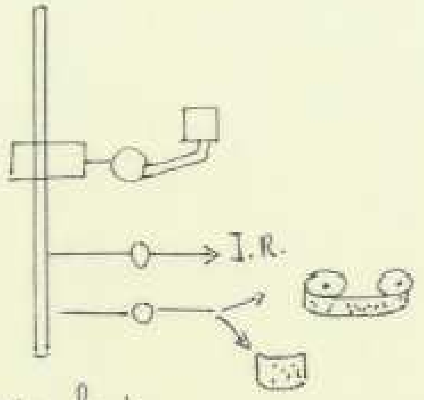
This is done by symbols conform to the machine’s reading. As previously described, the bases being the boards, data is transcribed to the computer in the form of electrical tension. Lack of passage through the hole of the board prevents a precise circuit from continuing. This all-or-nothing state can only occur in binary form, an arithmetical system of base 2.

### VI – 3 – 2 – Memory function

The basic organ of a computer where calculations are done is called the central unit.

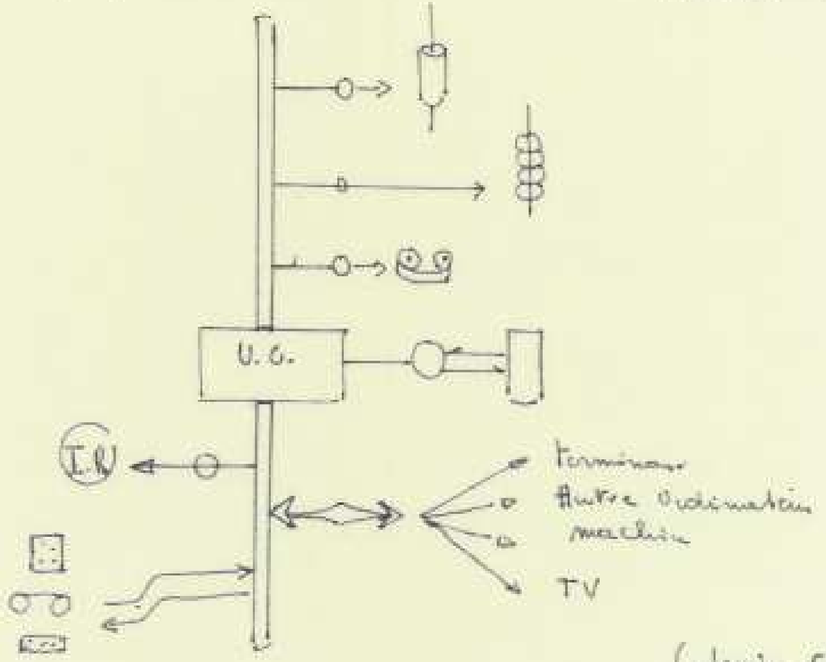
Before treatment by the computer, all data must be put in memory (capacity varies from ten thousands to several millions characters). Each memory position is filed in the computer. Auxiliary memories are only in contact with the exterior when passing through the central memory (see drawing n° 56 c).

Access time is the time needed to release the memorized information. The principle of reading in the computer’s organ is that of the magnetic core crossed by two conductors, each of them carrying half the intensity of the polarity toggle.



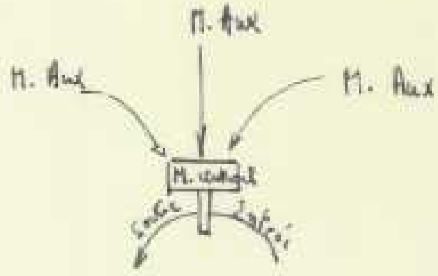

périphérique à type lent.

(dessin 56 a)

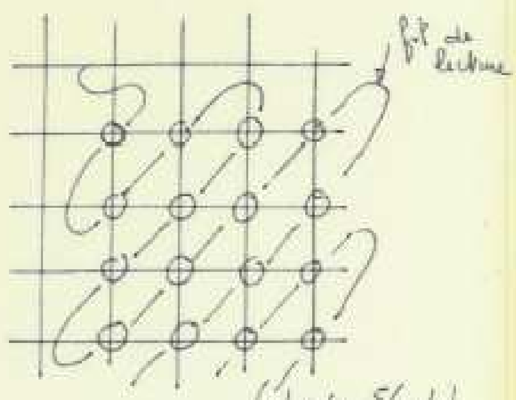



fonction mémoire.

(dessin 56 b)




principe. (dessin 56 c)




(dessin 56 d)

lecture

Only the cores having both intensities produce an all-or-nothing inversion (1 or 0) (see drawing n° 56 d).
The group of bits corresponding to a coded alphanumerical character or to a word is positioned on a same vertical.

VI – 3 – 3 – Central unit

The functions of the computer's unit are: And, Where and Now. One of the main functions is to search in the memory for factors upon which the operation will take place.
We provide the operation to the machine and where to find it. The information needed to run a series of specific operations constitutes a program.

Programs are presented to machine circuits as coded information which is placed in memory. The processing unit looks through the central memory one by one to find the program's instructions. Memories can first be placed in auxiliary memory (disk tape) and progressively changed in central memory.

Any process can therefore, be memorized and coded. The transition from one work to another is reduced to a change of program in the memory.

VI – 3 – 4 – Analysis and programs

Before analyzing an information, the computer must receive instructions in program form which is recorded in memory.

The phases are :

1°/ - Recording the program
2°/ - Recording the information to be processed
3°/ - Calculation
4°/ - Retrieving the results

VI – 3 – 4 – 1 – Programing

The program interpreted by the computer will be the algorithm of operations leading to the result.

To communicate orders to the computer, general programing languages are used which allow us to approach mathematical formulation (FORTRAN, ALGOL and for file maintenance IBM's COBOL and PL1).

It should be noted that one week of work is enough to analyze a language like FORTRAN. Therefore, the program can be done by everyone.

VI – 3 – 4 – 2 – Compilers

Instructions translated into advanced language serve as a data base for compilers which translate them into an assembly language:

1°/ - recognition of the key word
2°/ - syntaxical analysis of instructions
3°/ - setting up the tables of variables
which would be used to store the progressive or definitive values.

The result is an assembly language of the user's program in the form of lists using symbolic languages inferring variable addresses and the memory's geography or diagnosis errors, if any.

Often several symbolic programs are compiled separately and once perfected, are assembled and connected.

Advantages :
- fast writing
- reduction in writing errors
- a diagnosis which facilitates perfection
- presentation of a simple program
- can be operated by various materials
- possibility for modification or extension

VI – 3 – 4 – 3 – Analysis

This is the group of studies that allow us to process the information.

VI – 3 – 5 – Our method (see drawing n° 57)

VI – 3 – 5 – 1 – Program

In memory we must have (see in the last chapter)

- Typical teeth (recorded in bits)
There will be 32 permanent and 20 temporary ideal and theoretical teeth.

- Types of crowns used
The same information but with the ideal form of the ceramic cap, for example, or of a crown with holes or anchors for attachment.

- Metal to be used
Input : direct
elasticity
wear of the metal in saliva

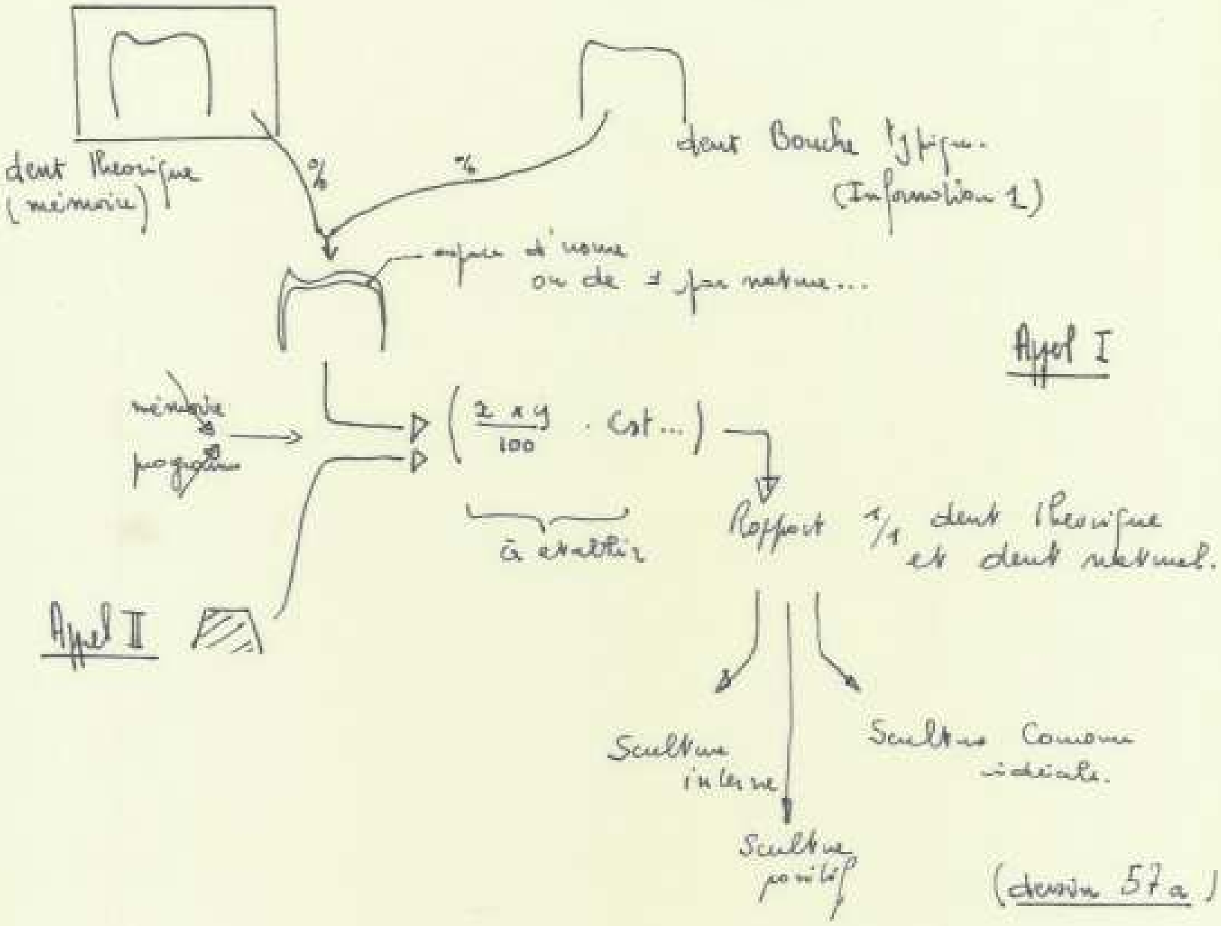
This can be recorded on disks in the form of bits, for example.

VI – 3 – 5 – 2 – Operation (see drawing n° 57 a)

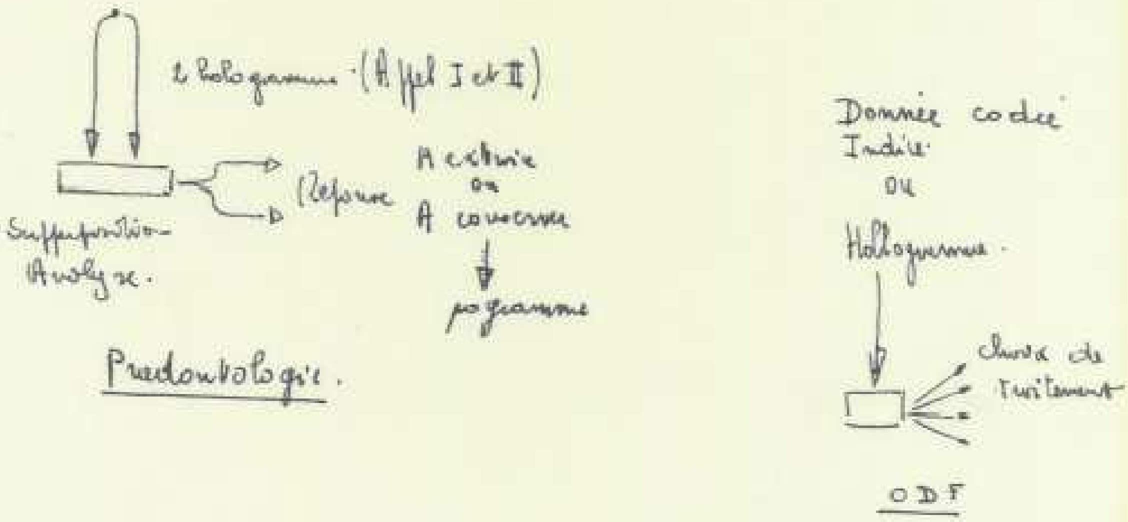
VI – 3 – 5 – 2 – 1 – Sculpting the exterior

- Information 1 : one or even x typical teeth are entered in the analyzed mouth. The computer notes the difference between theoretical and present teeth which is given as information and establishes the average relative wear of the cuspids… This value will be put in non definitive memory (see drawing n° 57 a).

- Information 2 : an analysis is made and, considering the established rules, the computer will adapt the theoretical tooth to the volume of the stump of the tooth to be crowned.




(dessin 57 a)




(dessin 57 b et c)

- Analysis :

Before sculpting the tooth, the computer reduces the theoretical data according to the program

- ● 1 theoretical tooth is reduced to real dimensions
- ● 1 reduction (1) of information comparison n°1 is recorded
- ● 2 reduction (2) if antagonistic metal or natural tooth is present
- ● 3 reduction (3) per chosen factor (mobility…loose tooth)
- ● 4 reduction (4) for chosen crowns (ceramic, etc)

- Output

● 5 expansion considering wear for metal materials

The result will be a modified theoretical tooth as nature would have created it in the time and manner we choose.

VI – 3 – 5 – 2 – 2 – Sculpting the interior

Information 2 analysis without modification will result in a sculpture of the impression. Then, while sculpting the interior of the crown the data can be increased theoretically thus permitting the passage of the chosen cement.

VI – 3 – 6 – Terminal

We cannot expect every individual to have a computer at home. A good solution is the use of the terminal.

VI – 3 – 6 – 1 – There are three main categories of terminals

- Data capture terminals: only data is transmitted.
- Information terminals: questions are input in order to receive information.
- Man-machine dialogue terminals: by typing on a machine, a code is transmitted which calls up a determined program then our information is transmitted, the computer returns it to us.

VI – 3 – 6 – 2 – Our case

We code : 1) – call gives response : I listen
2) – typical tooth of the chosen mouth is introduced
for example : information 1 { 2
{ 8
{ 5

then :
3) – computer does modification
4) – us : information 2 (crown stump)
5) – program : introduced

which gives 6) – output : (1) positive
dead time
(2) internal sculpting modification done
dead time
(3) external theoretic sculpture

VI – 3 – 6 – 3 – Theoretical drawing

(1) We see in ordinate the various operating times.
Information 1 then information 2 plus program

(2) Other choices (direct)
Here one has :
DFO theoretical data in memory. We send our practical data (angle,…) therefore : the terminal question (drawing n° 57 b)

PARO same (drawing n° 57 b)

VI – 3 – 6 – 4 – Summary

(drawing n° 58)

Our data are given by :

- the choice of program
- the example of the mouth’s typical teeth (equal information)
- the transmission of the carved stump (information 2)

In return, the computer sends us the cut
- of a positive

- of the crown’s interior
- of the crown

Storage of the impression is easy and repetition is indefinite without modifying the sculpting.

It must not be forgotten that the computer freely chooses the place where it will begin to sculpt the piece. In the case of the crown, we must precisely orient in three dimensions in order to avoid phase displacement. All that is needed is to coincide our sculpted impression with its photo on the hologram. This is very easy (verification of the piece).

The use of the terminal justifies its utilization in DFO and parodontology, not only for information purposes.

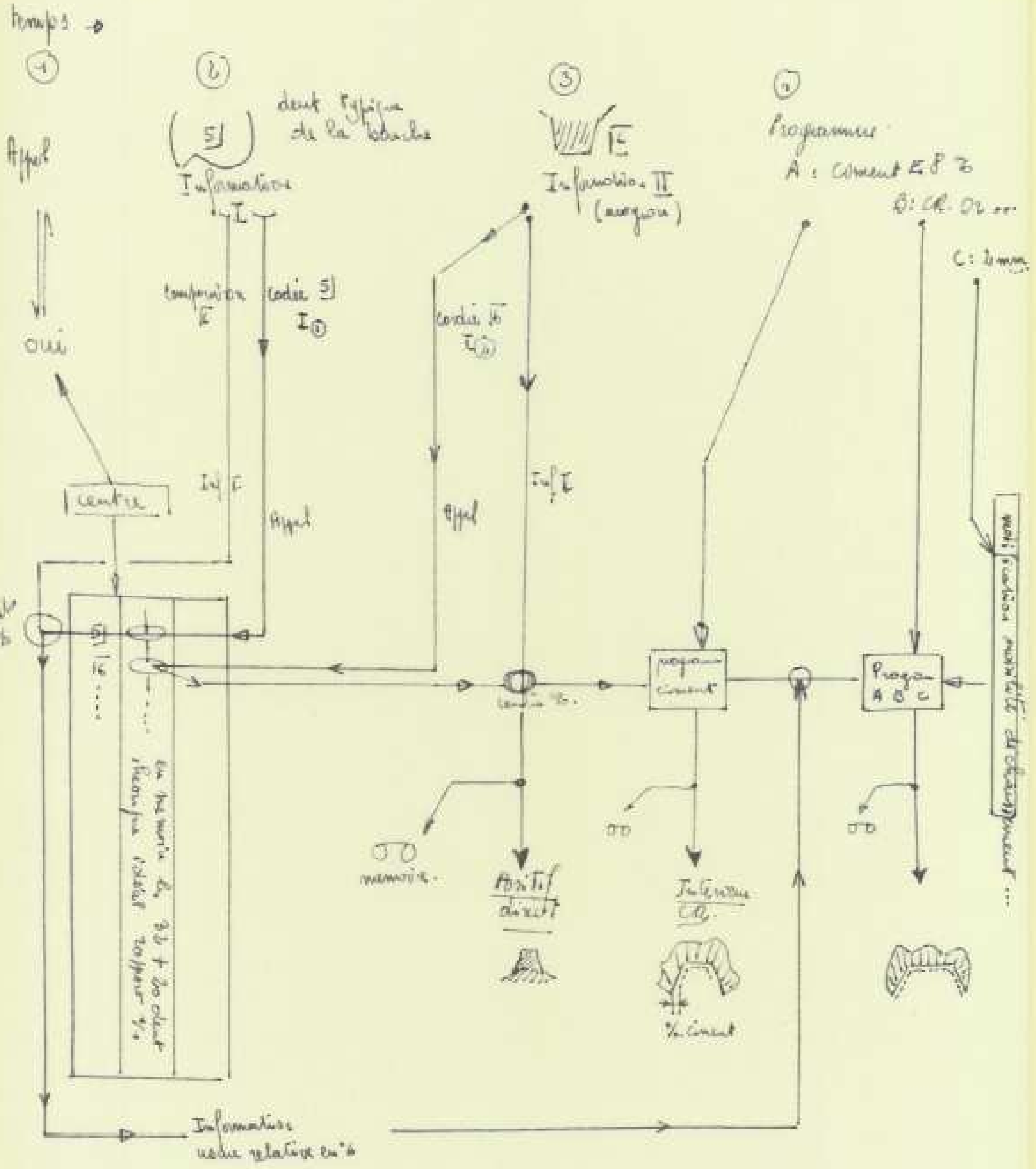



schéma d'induction d'une couronne de 16

(dessin 58)

# NUMERIC COMMAND OF MACHINE TOOLS

**- ORGANIZATION OF NUMERIC COMMANDS**
**- VARIOUS NUMERIC COMMANDS**
**- INFORMATION TRANSMISSION**
**- METHOD OF DISPLACEMENT NUMERIC MEASUREMENT**
**- FUNCTIONING OF NUMERICALLY-CONTROLLED MACHINE TOOLS**
**- STUDY OF MACHINE TOOLS IN CONTINUOUS POSITION**
**- CONCLUSION**
**- SUMMARY**

# CHAPTER – VII –

**Definition :**

Numerical command is an automation procedure that allows to guide a mobile mechanical organ or a position determined by an order. The position can be obtained by linear or angular displacement according to the degree of freedom of the mobile. The order is delivered in the form of cartesian or polar numerical coordinates.

We still have a point-by-point procedure but, considering the machine's precision, the action will be continuous as they approach one another.

The numerical command process can be used to displace any mechanical organ run by a engine.

Today we can say that 30% of manufacturing machines use numerical command (drill).
This kind of command allows production in small and large series with more ease than with manual command, especially on small machines.

## VII – 1 – ORGANIGRAM OF A NUMERIC COMMAND

The mobile organ includes so many placement axes, each with a engine that it has with degrees of freedom.
Each engine constitutes the terminal organ of one of the positions. The principle of the cervical command is:

-There is a constant comparison of the order position and the command signal sent to the engine according to the gap between the order position called error signal. We therefore have a "position sensor".

For us, orders are issued from a program tape which supports the translation into machine language of numbered dimensions brought on the drawing of the piece to be milled (for us the dimensions of holographic scanning).

Finally we have a comparator that gives an error signal. This signal acting on the engine reaches out to catch the position gap between the signal and the actual position.

When a numerically commanded machine has several command axes it often has as many axes with independent brain commands.

Systems also exist for positioning an X and Y table in which a single, brain commanded one is used successively to put x and y into position. Its advantage is time saved, the disadvantage is waste of time.

Even if there are 2 to 6 command axes, the tape (scanner) is unique. It supports orders intended for various brain-commands so that each one receives its own. Therefore you must have a good orientation.

## VII – 2 – VARIOUS NUMERIC COMMANDS

### VII – 2 – 1 – Introduction

We must obtain a continuous profile. Also, we apply particular importance to continuous command.

Continuous guide requires the coordinated command of various command axes, so that the route travelled passes by usual spots of the theoretical trajectory which are sufficiently numerous so that we are assured that the actual trajectory never deviates at a distance greater than tolerance. In addition to the brain-command, a great number of points on the trajectory must be coordinated. The guide moves along the trajectory.

Systems with absolute programing are those to which orders for position are given in the form of points coordinates which represent successive destinations of the mobile.

Relative programing systems are those to which position orders are sent in the form of components of operating displacements starting from an engaged position to gain the next one:

- absolute order
- relative order

While during scanning a numerical conversion is done, here an analogical (or analogical numeric) conversion occurs.

VII – 2 – 2 – System for absolute programming of orders

VII – 2 – 2 – 1 – Absolute scanning of orders and position can be analogical or numerical depending if the position is verified numerically (with transcoder) or is itself numeric.

VII – 2 – 2 – 2 – Absolute scanning of orders is related to displacement. It is not necessary to know the object's position; one only has to integrate its displacement in time (the so-called incremental sensor device starts if a displacement is X).

VII – 2 – 3 – Relative programing of orders

Only the closed mouth (verification) system interests us. The brain-command with absolute programing is the most satisfactory but also the most expensive.

**VII – 3 – TRANSMISSION OF INFORMATIONS**

In our technique, the machine reads and takes notes of the information, then executes the commanded operation according to instructions.

After programming, the machine's scanning is done with perforated cardboard or magnetic tapes.

With a terminal we cannot use perforated tapes so we turn to the video recorder and the magnetic tape (tape recorder also).
It is a magnetic layer (ferro-magnetic oxide) on a base, which will memorize the information by electromagnetic induction under the action of an electro-magnet. More than 7 electro-magnets can be scanned.

We can scan on a tape 50,000 to 100,000 lines per second. The scanning speed is the same as the recording speed.

In order to process a complete information, the machine requires more information than the one of a tape line. It is really the group of lines that forms a complete block of information.

- Example : (drilling) X = 200,000 {position of the table at the hole

| | | |
|---|---|---|
| Y = | 100,000 | { mark |
| K = | 18 | tool number |
| P | | drilling sequence |
| $Z_1$= | 7,000 | quick advance stopping point |
| $B_3$ | | broach speed |
| $A_4$ | | advance speed |
| $Z_2$ = | 120,000 | work advance stopping point |
| END | | End of the information block |

The machine usually explores all the information in bursts. It simultaneously arranges these informations in a memory circuit where they are retrieved to be translated for the concerned organs.

## VII – 4 – NUMERIC MEASUREMENT METHOD

Methods are:

### VII – 4 – 1 – Relative, incremental or by calculation

The movement of the carriage whose displacement we want to measure causes the information, always the same information to be sent each time this displacement reaches a determined value.

### VII – 4 – 2 – Absolute or coded method

A certain number of positions is defined along the carriage's displacement as for the first group but each of these positions is permanently defined by a code held by a measuring organ that is read by a bound system in the carriage. We therefore have the exact position in relation to the original.

In all these systems, we find rotating (photoelectric), inductive and capacity (or with black fringes) sensors but there are numerous other methods.

The numeric command's influence explains why I chose the computer. It operates in two ways, imposing certain conditions on machine tools and allows saving operating time.

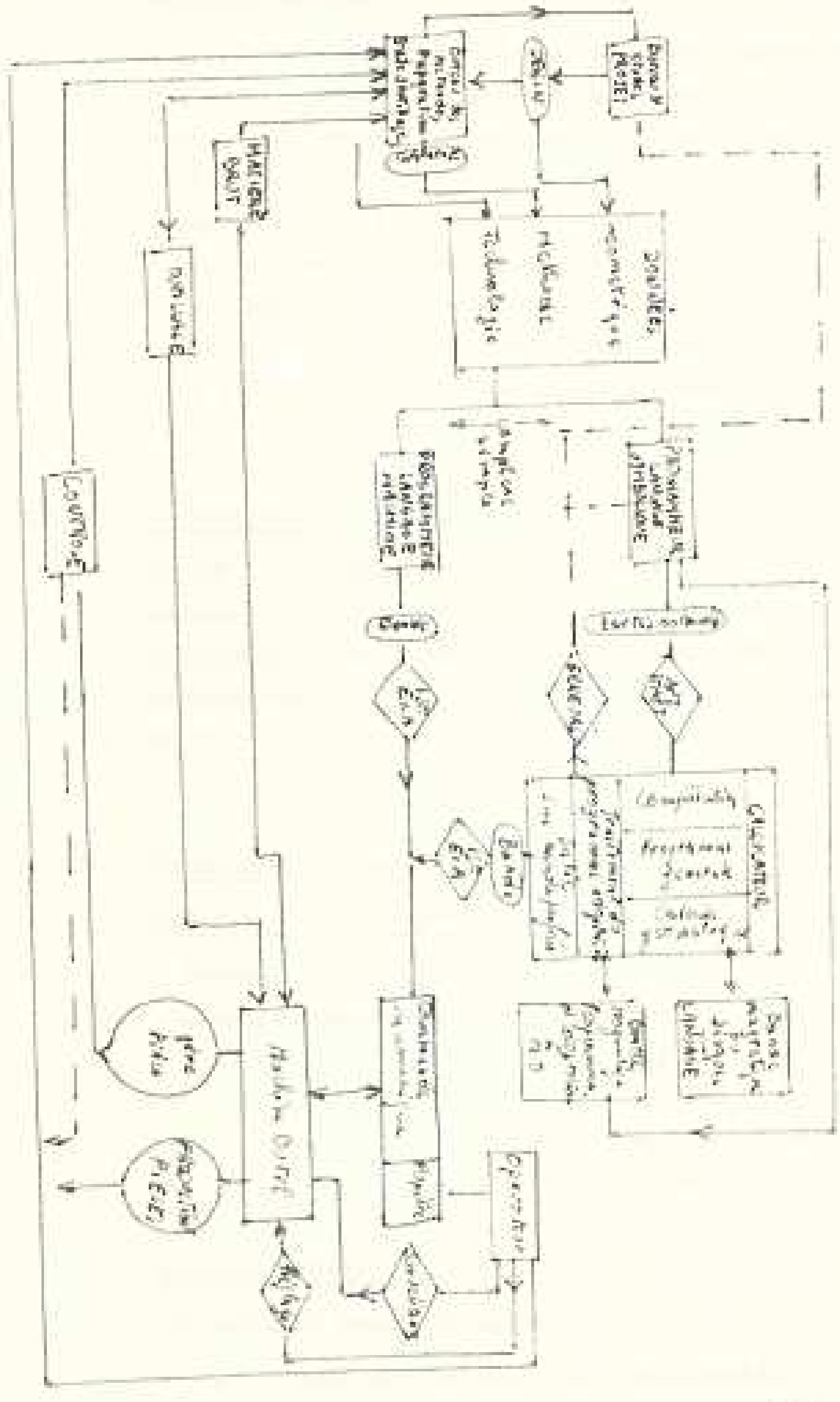
## VII – 5 – FUNCTIONING OF THE NUMERICALLY-COMMANDED MACHINE TOOL

(see drawing n° 59)

## VII – 6 - STUDY OF MACHINE TOOLS IN CONTINUOUS POSITION

### VII – 6 – 1 – Command system

Successive command of the machine occurs only if the previous order has been correctly executed.
This system which depends on the previous action is said to be sequential in opposition with the programed system, whose parameter managing the state is independent from the considered time. It is however defined by a program that communicates to the machine the instructions necessary for executing various operations (defined in an absolute way in recorded form for example).



commande numérique de M.O.

(Doreau) (demain 54)

VII – 6 – 2 – Characteristics

The following are characteristics of the continuous positioning system:

- use of a great number of numerical data
- implementation of a high speed command logic
- use of action organs with perfectly linear characteristics
- higher cost
- the user's contribution is very important and he/she must have extensive knowledge (this is where the prosthesist intervenes in our scale of ideas)
- use of systems in closed mouth is preferred

VII – 6 – 3 – The prosthesist

The prosthesist's role will be to prepare the machine so that it operates correctly. He/she will collect and program information and will become an expert in machine tools. His/her role will also be to make ceramics.

VII – 6 – 4 – Command processes

VII – 6 – 4 – 1 – The manuscript

- trajectory information
- other milling information : cutting speed
  broach speed
  advance speed
  type of tool's diameter
  moistening liquid

VII – 6 – 4 – 2 – Calculation of the trajectory

Calculation can be manual or automatic.

For us only automatic calculation is feasible.

The tape sent by the computer is magnetically recorded and transmitted to a universal calculator which defines the various trajectory points (minimal number of orders or circumference arches compatible with the imposed tolerance and the desired finish) of the tool wear and line defaults. Instructions regarding translation speed advances are found on the tape exiting the converter, where the jaws must stop. Because the trajectory is complex, we must substitute empirical curves taking into account the required precision and the chosen finish. This means that we must define hundreds even thousands small fragments approaching the theoretical trajectory which require the recording of a comparable number of information blocks.

### VII – 6 – 4 – 3 – Calculation of interpolation

Information recorded on the tape corresponds to a direct follow-up of points whose juxtaposition defines an inscribed polygonal contour in the real trajectory. We must have a continuous contour, thus interpolation. The calculators are interpolators.

### VII – 6 – 4 – 4 – Recording information

This appears in a series of simultaneously elaborated incremental impulsions. Each tissue corresponds to a different axis. In a given time, it has as many impulsions as displacements in the considered direction require elementary steps. In view of this abundance, we choose magnetic tape.

The interpolator should not be located at our office but in a specialized center.

### VII – 6 – 4 – 5 – Command of the machine

Incremental-type signals are applied for each axis to a position comparator by comparison with the position actually occupied by the tool and transmitted by means of an appropriate sensor. Following amplification, the comparator creates an error signal which is used to command an action organ that is sensitive to the error signal until the moment the prescribed position is reached.

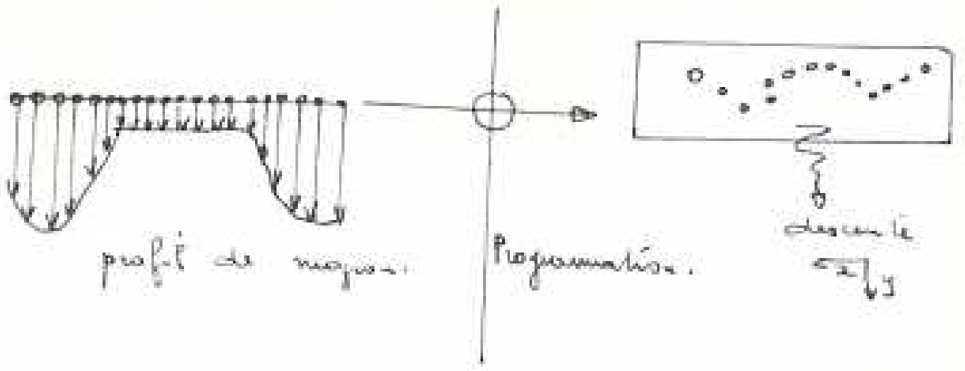
Note : this command is currently expensive and complicated but interesting. For a 1 cm side square diagonal, the speed of each axis equals 2.5 cm/s which requires 1,000 to 5,000 impulsions/second. This corresponds to increments of 25 to 5 μ. For 5 μ we would need 15,000 bits per second or for a 2 cm side, approximately 20,000 bits. This way, one single impression requires approximately 200,000 bits maximum/second and a total impression requires 2 millions bits. This is perfectly acceptable for a computer and for magnetic tape with fast unwinding.

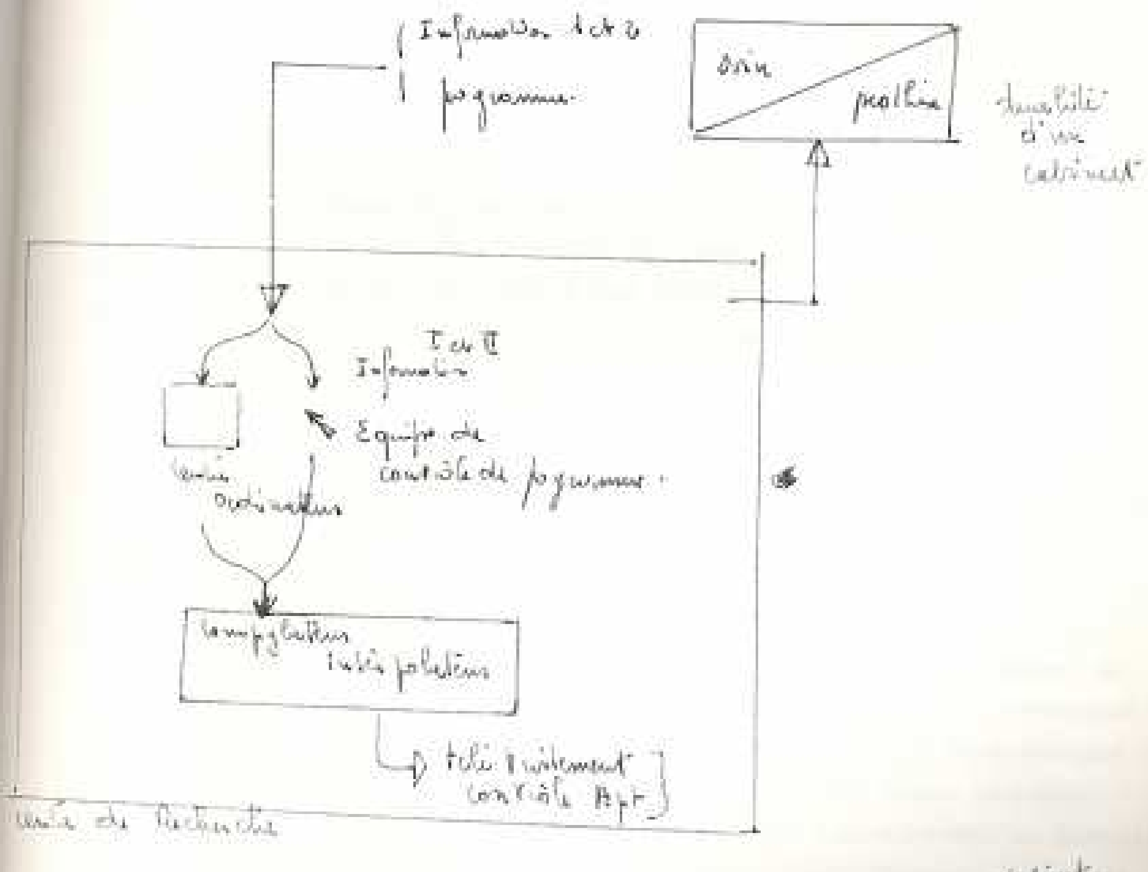
To begin, we can reduce the amount of information by using an integrated numeric interpolator which lets us decrease the number of programmed values by deducting from these the intermediary corresponding values.

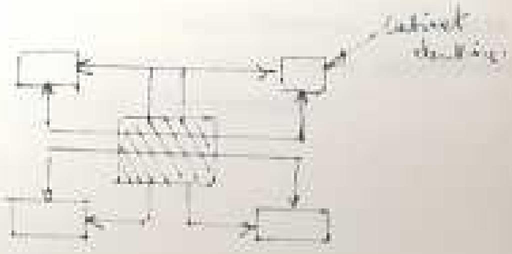
I would say (as does IBM) that one cannot have numeric programing without precise knowledge of programs such as for class II Autostop, Adapt and Apt and for class III Romance, Teckpop and Autopol. These programs are proposed for use in machines that work either point by point, in two dimensions and two + two dimensions or by two or three-dimensional contouring.

## VII – 7 – CONCLUSION

In addition to our computer, we must acknowledge treatment of our information II by a machine tool type program using numeric commands such as the three-dimensional Apt programs. Everything is tied to the idea of interpolation (see drawing n° 60).


Programmation.
descente





Each program often written in Forman is acceptable in a numerically commanded machine. In our case they are transmitted through teleprocessing.

VII – 7 – 1 – Current problems

Given the maximum precision we require from our machines, we must admit that, in addition to geometric and cinematic parameters of milling operations, technological parameters must be incorporated such as the choice of tools, the operation sequences and the image conditions. This problem is called integration of technological data in numerical command programs (Except in Germany, for example).

As we do not always know the degrees and milling properties of materials and the cutting stability, we must compensate by determining optimal milling conditions with an adaptable command (see drawing n° 60).

It is nevertheless good to note that we are presenting materials (gold - steel) with reduced or known milling problems.

By teleprocessing huge calculators, a specialized team would prepare and modify the program's data. I base this principle on the fact that the central unit would quickly deal with the problems whereas the peripheral units (input - output) would slowly take care of each problem. So we save time and reliability. Nothing prevents a dentist to control identification, graphic means and transmitted program quality on his closed-circuit TV by superposing it on the impression (cathodic computer screen).

VII – 7 – 2 – Unisurf procedure (Renault)

VII – 7 – 2 – 1 – Delay in response

- scanning : a few minutes
- milling : a few hours for a surface of several m²

VII – 7 – 2 – 2 – Precision

$10^{-4}$ (1 mm → 1 µ)

VII – 7 – 2 – 3 – Conception : mathematically easy

Conception is independent with regards to the referential so the definition of curves and surfaces is independent from the chosen referential. This property allows numerous simplified calculations which correspond to projection, translation and rotation operations which are needed for milling and designing.

The Unisurf procedure allows an operator who does not have any mathematical knowledge to create the form of a curve or a surface in a very short time and with a precision of around $10^{-4}$ to $10^{-5}$ and to modify it to his liking. For example, the speed allows production of a pin (for example) in a few minutes.

Conclusion :

For a 10 cm² surface with a precision of 10 (dentists work with a precision of 500 to 100 µ), the maximum time is 1.30 hours (spacing: 10 µ per character) and 1.30 hours for 1 cm with precision of 1 µ. Milling time depends on the required precision (character spacing).

**VII – 8 – SUMMARY**

Considering the treatment of informations I and II and the program sent by teleprocessing (terminal) which consists in:

- the type of damaged metal
- the type of work selected (crown, cap, etc..)
- the desired surface and its precision

In return our central team returns the coded program (Apt) for the machine by the terminal, with a sound recorder.

The central team has a maximum purpose and is divided into mathematicians (theoretical and specialized in computers), materials specialists, sculpting specialists and finally dental theoreticians.

The method's advantage is that it finally allows the application of theoretical ideas even in the most remote dental practices.

The central block would modify the program and control input and output. The dentist would only have to control the milling and its reproduction on the hologram and at the beginning (what role for the prosthesist ?).

Now we will look at the machine used for sculpting.

# MACHINE TOOL

**- INTRODUCTION**
**- ELECTRO-EROSION**
**- ELECTROCHEMISTRY**
**- ELECTROFORM**
**- CHEMICAL MILLING**
**- ULTRASOUND**
**- SPECIFIC HIGH-ENERGY PROCESSES**
**- LASER**
**- MILLING**
**- CONCLUSION**

# CHAPTER - VIII –

**INTRODUCTION**

The proposed micro-milling is divided into two parts. The first one, the unconventional type is divided into 7 parts. The second one represents the classic methods and is divided into 2 parts.

For unconventional milling methods we did not want to modify the character of Mr MARTY's book [300]. We give a summary of this work without modifying the phases which were done by specialists…Only the last chapter about milling comes from METRAL's work [301] and is a classic regarding milling.

Milling a part
Milling consists of removing matter from a piece in order to give it the shape and dimensions of a determined product.

We will study various avant-garde techniques: (electro-erosion, electrochemistry, electroform, chemical milling, ultrasound, high energy processes such as electronic bombardment and the laser).

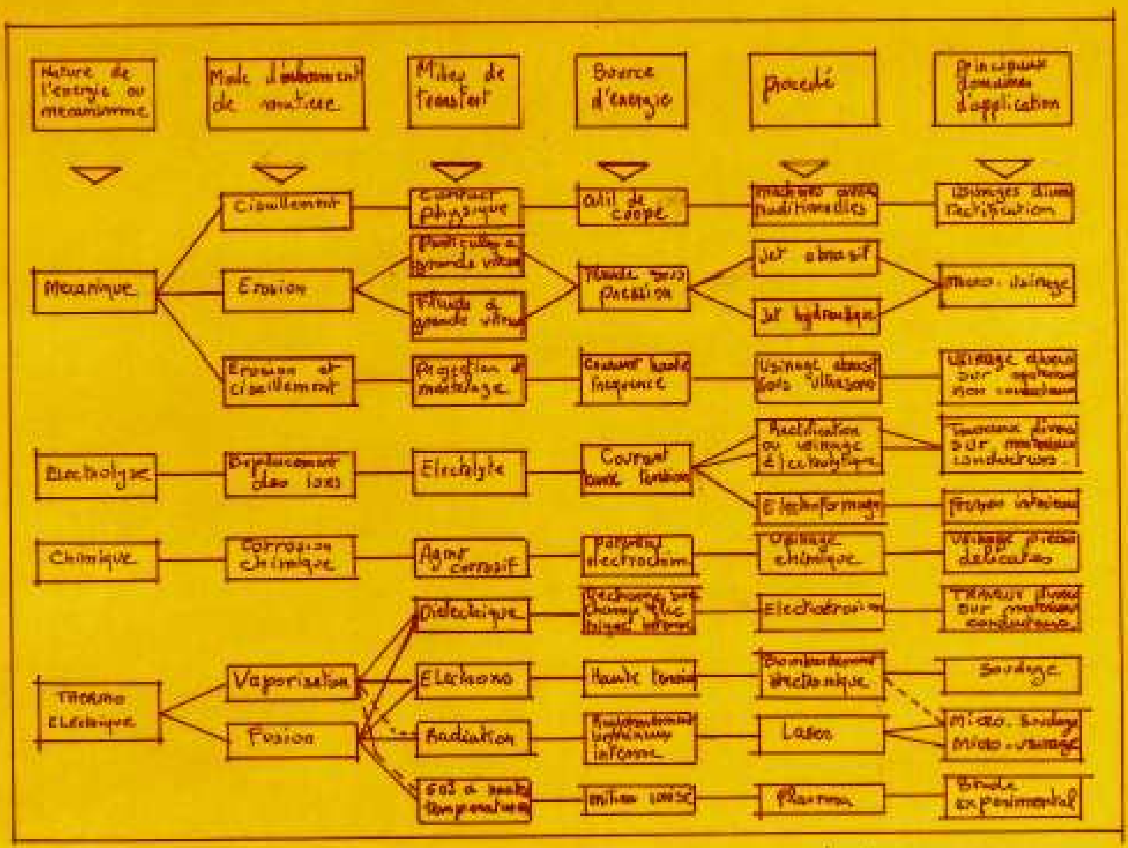
We will then try to draw from it an application more particular to us and in a summary we will reunite C N and milling. (drawing n° 61 a).

**VIII – 1 – ELECTRO-EROSION** [300]

VIII – 1 – 1 - Properties

-great capacity for milling hard or refractory metals or alloys (steel, tungsten carbide or stellite tools)

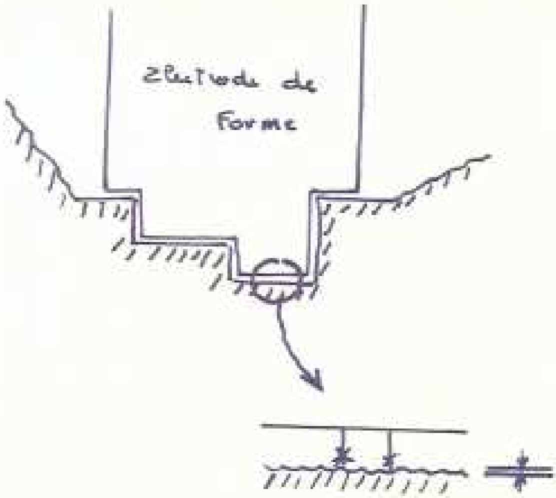
-ability to do automatic form reproduction. The matter located on the whole surface of an electro-part to be milled is removed. This means that the form of the electro-part will be the one obtained in the part to be milled (see drawing n° 62 a).




(dessin 61a)

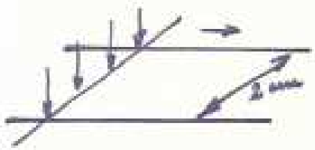
| | Vitesse de pénétration | Tension | Concentration d'électrolyte | Température d'électrolyte | Surface à usiner | Pression d'injection | Rendement de dissolution | Effet de la Trempe |
|---|---|---|---|---|---|---|---|---|
| Courant | Influence proportionnelle directe | Sans influence | Influence inversement proportionnelle et indirecte par augmentation du rendement | Influence proportionnelle et indirecte par diminution du rendement | Influence proportionnelle directe et linéaire | Influence inversement proportionnelle indirecte par augmentation du rendement | Influence inversement proportionnelle et directe | Influence proportionnelle directe, généralement peu importante |
| | ↗ | ----- | - - ↘ | - - ↗ | ↗ | - - ↘ | ↘ | ↗ |
| Gap | Influence directe importante et inversement proportionnelle | Influence proportionnelle directe | Influence importante proportionnelle et directe | Influence proportionnelle directe peut être compensée par diminution du rendement | Sans influence | Sans influence notable | Influence directe et proportionnelle | Influence directe et inversement proportionnelle peu importante |
| | ↘ | ↗ | ↗ | ↗ | — | - - ↗ | ↗ | ↘ |
| Rendement de dissolution anodique (cas du $NaNO_3$) | Influence proportionnelle directe | Sans influence notoire | Influence proportionnelle directe | Influence directe et inversement proportionnelle | Sans influence | Influence proportionnelle directe | | Influence directe et inversement proportionnelle peu importante |
| | ↗ | | ↗ | ↘ | — | ↗ | | ↘ |

(dessin 61b)

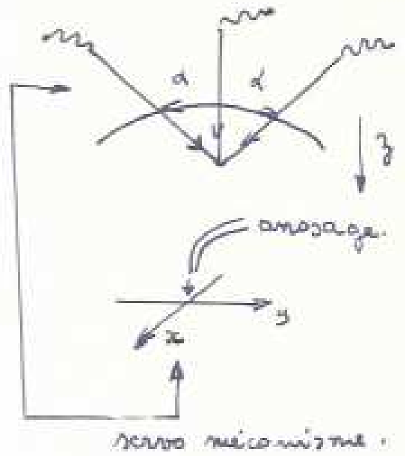



**Electro erosion** (dessin 62 a et b)

Nous : générateur à impulsion (courant ou isoenergetique)
electrode très fine.




pour une précision de 10μ sur 2 cm
→ 100 aller et retour
décalage de 2 mm seulement




Rendement f(c) de intensité
refroidissement
du liquide E.L.

(dessin 62 c)

With the impulsion generators we reduce wear on the electrodes. This allows milling general forms. We can therefore work in so-called three-dimensional surface categories by simple immersion of a form electrode.

VIII – 1 – 2 – Physical principle (drawing n° 62 b)

Removal of matter is done by means of electrical discharges. A liquid contains free ions. Under the influence of applied tension between electrodes, the ions will move around (very tough for electrolyte liquid).

If we apply a tension in between these electrodes that is greater than the straining tension and is set by the distance of the electrodes and the insulating power of the dielectric, a discharge will begin at the spot of the strongest electrical field. An ionized canal is formed which is a conductor for the electrical power current.

From the ionized canal we move to a large passage of power then to the ejection of the eroded metal. The third phase tallies with the second one and continues.

VIII – 1 – 3 – Assembly

Various assemblies are possible according to the generators used. Their factors are: provide strong tension, limit current discharge, high duration and frequency repetition. These generators can be current or iso-energetic impulse-type where a well-defined quantity of matter is removed. This guarantees optimal conditions with regards to quick milling, good surface quality and milling at a regular surface.

For this type of generator, energy distribution can be parallel or by separate output (much faster: if there are 6 electrodes, it will work 8 times as fast). We should point out here that super-finish generators allow the use of micro-electrodes but with large energetic impulses (we go from 80 V to 250 V).

VIII – 1 – 4 – Description of the machines (drawing n° 62 c)

The machine consists of a column with a working head that has a brain-mechanism acting on an electrode carrier piston which ensures displacement on a single axis. In some cases, the TV can pivot which allows orientation of the working axis. In front of it, there is an adjustable object carriage (precision of 10 μ per 40 cm at 1 μ). The brain-mechanism always keeps one electrode the appropriate distance away from the part (electro-hydraulic, electro-mechanical command).

There is a in depth stop mechanism. There should be constant moistening (di-electrical liquid).

VIII – 1 – 5 – Implementation

Not interesting.
Milling speed depends on intensity, the liquid plays an important role (phenomenum turn-over, cooling of the part).

Characters will be specified during the section on numerical commands tied to this chapter. Let us just say that its precision is 5% from the sparking distance (approximately 1 to 2 μ).

VIII – 1 – 6 – Application

The system allows preparation of moulds of the part to be cast. This would be a good procedure for making ion metal crowns as I mentioned above.

Numbered successive moulds would be produced with a maximum precision of 5 μ.

## VIII – 2 – ELECTRO-CHEMICAL MILLING

VIII – 2 – 1 – General study

Metal is removed with anode in order to create a difference in potential between both electrodes. The amount removed is proportional to the power amount and the gram valence of the element and must therefore be precise (see drawing n° 63 a).

So in the case of an alloy, the following formula would have to be used.

$$\varepsilon \frac{a}{n} = X_1 \frac{A_1}{n_1} + X_2 \frac{A_2}{n_2} + X_3 \frac{A_3}{n_3} \ldots$$

thus, to be certain of the metallic composition.
The electrolysis mechanism is presumed known…Each factor (migration, diffusion, conversion) must be carefully reviewed.

VIII – 2 – 2 – Dynamic study

The gap which is the maximum step in the action is the best yield space. We tend asymptotically toward this value which means that electrolytic milling does not require a warning from the electrode carrier since it automatically regulates power tension and the previous speed remains constant (10 µ and more).

To obtain constancy in this space, waste evacuation and removal of passive layers must be maintained, as in WILLIAM's idea regarding electrolyte injections.

VIII – 2 – 3 – Practical considerations

Metal removal also follows FARADAY's rule but the yield is also linked to dissociation of the electrolyte and the nature of the metal.

Determining the shape of the tool determines the shape of the obtained sculpture. The tool's shape must match the shape of the impression to be done. So we must know:

| Materiau | Epaisseur mm | Gaz | Vitesse m/mn | Largeur de découpe mm | Zone affectée |
|---|---|---|---|---|---|
| Acier inox | 0,7 | $O_2$ | 2,70 | 0,15 | 1,04 |
| | 1 | $O_2$ | 2,10 | 0,12 | 0,53 |
| " 304 | 1,5 | $O_2$ | 1,40 | 0,13 | 0,53 |
| | 2 | $O_2$ | 0,50 | 0,14 | 0,65 |
| | 3 | $O_2$ | 0,30 | 0,40 | 2,28 |
| " 316 | 4 | $O_2$ | 0,30 | 0,42 | 3,32 |
| ACC 1010 | 3 | $O_2$ | 1,00 | 0,40 | 2,50 |
| Acier doux | • 1,5 | $O_2$ | 1,70 | 0,13 | 0,64 |
| | • 4 | $O_2$ | 0,45 | 0,15 | 1,60 |
| Fer blanc | 0,3 | $O_2$ | 6,90 | 0,14 | 2,74 |
| Alliage special NICOMO | 0,4 | $O_2$ | 4,70 | 0,21 | 0,52 |
| Acier inox + film en plastique | 1 | $O_2$ | 1,65 | 0,12 | 1,00 |
| Titane pur | 0,8 | air | 1,90 | 0,20 | 2,00 |
| Pin | 4 | air | 8,20 | 0,30 | 1,30 |
| | • 10 | air | 2,60 | 0,23 | 0,46 |
| | • 18 | air | 0,75 | 0,31 | 0,45 |
| Frene | • 9-9,5 | air | 17 | 0,23 | 0,87 |
| | • 18 | air | 0,50 | 0,48 | 0,50 |
| | 20 | air | 0,40 | 0,54 | 1,4 |
| Triplex | • 4 | air | 8,75 | 0,22 | 0,83 |
| | • 10 | air | 2,00 | 0,21 | 0,37 |
| Bois | • 9-9,5 | air | 2,35 | 0,16 | 0,43 |
| Aggloméré | • 11 | air | 0,75 | 0,32 | 0,40 |
| amalit | • 3 | air | 5,20 | 0,13 | 0,19 |
| Plexiglas transparent | • 3 | air | 5,00 | 0,33 | 1,07 |
| | • 6 | air | 1,50 | 0,157 | 0,76 |
| | 9 | air | 1,30 | 0,40 | 2 |
| | • 30 | air | 0,15 | 0,54 | 1,12 |
| Plexiglas mat | 3 | air | 3,70 | | |
| | • 6 | air | 1,90 | 0,23 | 0,51 |
| Papier | 0,07 | air | 516 | 0,06 | |
| | 0,1 | air | 360 | 0,06 | |
| Tissus 3 couches | 4 | air | 8,3 | | |
| 53 couches | 9 | air | 2,3 | | |
| Tissus synthetique 29 couches | 9 | air | 1,8 | | |
| Caoutchouc 2 couches | 1 | air | 20 | | |
| | 2 | air | 5,7 | 1 | 1 |
| | 0,02 | air | 500 | 0,06 | 0,2 |
| Feuille PVC | 0,05 | air | 320 | | |
| | 0,15 | air | 105 | | |
| Element prefabriqué | 10 | air | 0,5 | 0,4 | 0,6 |
| Cuir 3 couches | 5,5 | air | 2,8 | 0,5 | 1,5 |
| Polyurethane | 200 | air | 0,5 | 4 | |
| Verre | 2 | | 2,9 | | |
| | 3 | | 1,8 | | |
| Eternit | • 3,5 | air | 0,30 | 0,15 | 0,19 |
| | • 14,5 | air | 0,10 | 0,25 | 0,45 |
| Formica | • 1,5 | air | 9,00 | 0,09 | 0,32 |

TABLEAU XIII – Résultats de découpe au laser à $CO_2$ obtenu dans les laboratoires O.I.P avec une puissance de sortie du laser de 400 watts (décembre 1969)

• Résultats obtenus avec un laser de 300 W de configuration speciale en mars 1970

(dessin 63 b)

TABLEAU III – Taux d'enlèvement théorique pour une intensité de

| Métal | Valence | Masse atomique | Masse spécifique | Enlèvement de matière |
|---|---|---|---|---|
| | | | gr·cm⁻³ | cm³ mn⁻¹ |
| Aluminium | 3 | 27 | 2,67 | 2,06 |
| Beryllium | 2 | | 1,85 | 1,50 |
| Chrome | 2 | 52 | 7,19 | 2,25 |
| | 3 | | | 1,51 |
| | 6 | | | 0,75 |
| Cobalt | 2 | 59 | 8,85 | 2,05 |
| | 3 | | | 1,37 |
| Niobium | 3 | | 8,57 | 2,16 |
| Columbium | 4 | 93,1 | 12,7 | 1,69-1,34 |
| Cuivre | 1 | 63,6 | 8,96 | 4,69 |
| | 2 | | | 2,20 |
| Fer | 2 | 56 | 7,86 | 2,21 |
| | 3 | | | 1,47 |
| Magnésium | 2 | 24 | 1,74 | 4,94 |
| Manganèse | 2 | 55 | 7,43 | 2,28 |
| | 4 | | | 1,15 |
| | 6 | | | 0,77 |
| | 7 | | | 0,66 |
| Molybdène | 3 | 96 | 10,22 | 1,95 |
| | 4 | | | 1,47 |
| | 6 | | | 0,98 |
| Nickel | 2 | 59 | 8,90 | 2,11 |
| | 3 | | | 1,36 |
| Silicium | 4 | 28 | 2,33 | 1,87 |
| Argent | 1 | 107 | 10,49 | 6,39 |
| etain | 2 | 119 | 7,30 | 5,05 |
| | 4 | | | 2,52 |
| Titane | 3 | 47 | 4,51 | 2,19 |
| | 4 | | | 1,65 |
| Tungstène | 6 | 184 | 19,3 | 0,93 |
| | 8 | | | 0,74 |
| Uranium | 4 | 238 | 19,1 | 1,82 |
| | 6 | | | 1,22 |
| Vanadium | 3 | 51 | 6,1 | 1,74 |
| | 5 | | | 1,05 |
| Zinc | 2 | 65 | 7,13 | 2,85 |

(dessin 63 a)

- the inter-electrode space
- the electrolyte's discharge
- the line of power current of the electrical field that allows variations to be taken into account.

The surface condition is of very high quality providing we consider each parameter: discharge, type of electrolyte, power density and type of alloy (see drawing n° 64 a).

VIII – 2 – 4 – Implementation

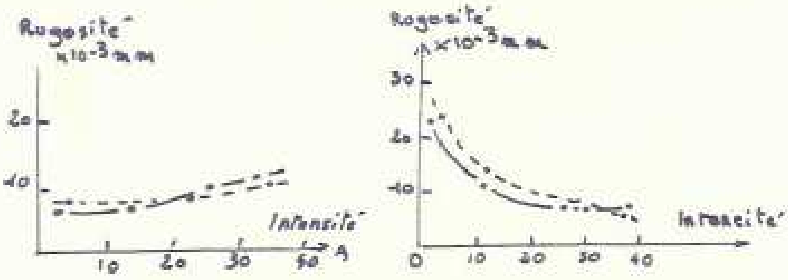
For an action the various parameters are:

- speed of penetration
- tension
- concentration of the electrolyte
- temperature of the electrolyte
- surface to be milled
- injection pressure
- dissolution yield
- soaking effects

The advantage of this procedure is no wear on the work tool, suppression of classical rough draft and finishing operations, milling of treated materials which avoids any ulterior deformation, remarkable surface condition (1 μ CLA), excellent precision obtained in rectification (10 μ) and drilling speed (see drawing n° 61 b).

## VIII – 3 – ELECTROFORM

This involves provoking an electro-deposit on a so-called master form, also called nucleus, mandrel or matrix and which is completely removed after milling the exterior surface (drawing n° 64).

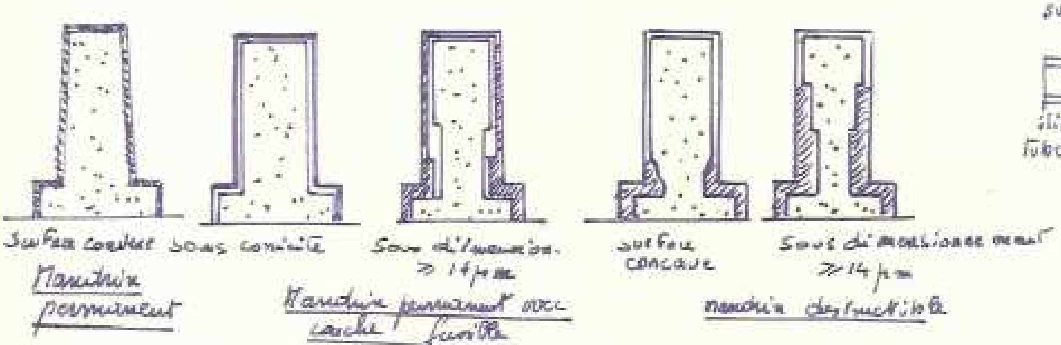



Acier doux    Acier inoxydable

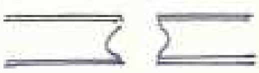
Variation de la rugosité en fct de l'intensité

(dessin 64a)

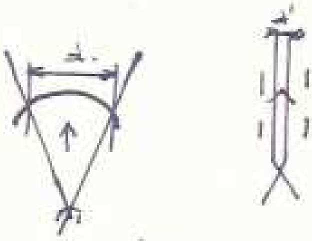

(dessin 64b)

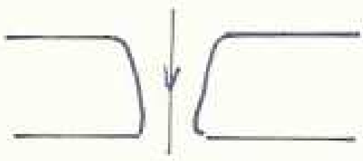

(dessin 64c)



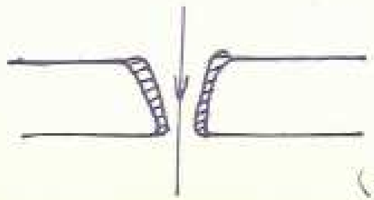
(dessin 64d.)




(dessin 64e)



(dessin 64 F)



(dessin 64 g.)

VIII – 3 – 1 – Advantages and disadvantages

VIII – 3 – 1 – 1 – Advantages

The deposit forms a body with its nucleus and take the exact forms of the lease relief. This is how we use this process for the micro-groove matrixes (i.e. the precision).

We can produce large quantities of parts with a very high degree of dimensional precision. We are only limited by the milling of the matrix.

Hollow forms can be made (see drawing n° 64 b).
Creation of parts of any dimensions can be done.
Electroform ensures the creation of sandwich materials, formed from the most varied metals. Tolerance is in regard to the material removed.
Thin cell walls are possible, if desired.

VIII – 3 – 1 – 2 –Disadvantages

- Higher prices if thickness is more than 1 cm
- Slow deposit: 0.5 mm/hour

VIII – 3 – 2 – Choice of the matrix (see drawing n° 64 c)

VIII – 3 – 2 – 1 - Permanent matrix

This is what we re-use once the part is formed. A beam must be respected to remove the part or there must be a difference in thermal dilation for this removal.

VIII – 3 – 2 – 2 – Permanent matrix with weak layer

If the details do not allow removal, we cover it with a thin layer of tin or of graphite wax which upon fusion allows us to remove the part.

### VIII – 3 – 2 – 3 – Destructible matrix

If we can remove the part, we use alloys with a low fusion point: plastic, wax, etc…

## VIII – 3 – 3 – Conception of the matrix

### VIII – 3 – 3 – 1 – Properties

- Milling capacity
- Aptitude for receiving the positive film
- Separation method
- Thermal lengthening coefficient
- Nature of the deposited metal
- Superficial hardness
- Soldering ability
- Price

The output angles on the matrix must be made as large as possible to avoid modules and arborescence. The input angles on the matrix will be made with as small a ray as possible to do the deposit.

- Scratches must be avoided
- The milling of the part must be done with its matrix.

## VIII – 3 – 4 – Materials useable with the matrix

- Aluminium (subject to corrosion)
- Stainless steel (2 µ minimum)
- Plastic material (galvanoplasty)
- Alloy with low fusion point (expensive but recoverable, bismuth, tin) after that, the matrix is eliminated.

## VIII – 3 – 5 – Electroformed materials

What must we know ?

- Mechanical and physical properties
- Resistance to corrosion
- Even deposit

Internal constraints should be noted (possibility of explosion).
We can use 8
- copper
- nickel cobalt
- cobalt tungstene
- chrome
- iron
- silver, gold (weak thickness)

It must be noted that no system can replace this idea. Impurities are obtained that can be eliminated by a precise study.

## VIII – 4 – CHEMICAL MILLING

This involves the dissolving of certain metals in an appropriate, aggressive solution (manufacturing of imprinted circuits).

### VIII – 4 – 1 – Implementation

Certain parts of the metal must be subjected to corrosion so that the other parts can be preserved.
We must admit the existence of a mask, therefore:
- preparation of the surface
- elaboration of a mask
- chemical milling
- cleaning and control

### VIII – 4 – 2 – Elaboration of the mask

It must be resistant to aggressive solutions. It must adhere to the part for a sufficient amount of time so that the removed thickness is reduced. It must be possible to cut it.

This usually involves painting, varnishes and rubber or photosensitive resins.
A voluntary error called “shrinkage” is intended to consider that the dissolution is not rigorous.

If we want a precision of $1/100^{th}$, photosensitive resins are valid.

The exposure method is admissible (negative) even in our case (drawing n° 64 d)

### VIII – 4 – 3 – Technical result

The dissolved thickness depends on the metal. Anyway, let’s say that 2 mm to 10 mm can be reached.

## VIII – 5 – ULTRASOUNDS

These are the waves comprised between 16 K Hz and 1000 M Hz.
Mechanical vibrations are transmitted by charging molecules which oscillate around their resting position. They develop one to one.

The propagation can be analyzed (KIEFFER).

The interface phenomenum should be noted. This means that the vibrations can transmit from one environment to another. There is a classic angle of incidence. Thus here we find the laws of reflection and refraction.

One can therefore speak of an “optical” ultrasound in the sense that research generally has given a signification to the terms: reflection, refraction, focalisation within acoustics.

VIII – 5 – 1 – Ultrasound wave generator

Numerous possibilities exist, transducers are numerous (KIEFFER). Let's mention the work of CRAWFORD.

VIII – 5 – 2 – Visualization of ultrasounds and other applications

This is done in different ways (SCHLIEREN's method). We note the role of the ultrasonic camera. It is based like our analysis and here again a scanning by cathode ray tube gives good information (see drawing n° 65 a).

With good results we obtain a precision of 200 μ which can be pushed even further.

They can be used to increase the electrolytic deposit speed [Chapter VIII-3].

The application based on echo detection is essential for us. The Navy sonar uses it. Ocean floors can be detected as well as schools of fish… Drawing n° 65 b gives a precise idea of ultrasonic penetration.

It is therefore very important to know that in the area of ultrasounds the laser can electively reflect itself on certain zones. The therapeutic domain is enormous and will hopefully be the subject of many future researches.

VIII – 5 – 3 – Abrasive milling by ultra-sounds

It allows the passage in any form where the traditional techniques do not.

A machine is composed of a generator with a low frequency current, an electro-acoustical converter, an amplifier or half-wave cone and a milling tool or sonotrope in the form of a double cylinder whose amplification relation is only a function of the work to be done. It is easily interchangeable and is attached by threads.

The parts to be milled are fixed on the abrasive recycling group that can be adapted to a table with crossed movement whose XY motion is commanded by a micrometer.
Where there is a large surface to be milled, we proceed by successive inputs with very high precision using a crossed movement table.

An abrasive must obviously be added (usually boron carbide). It is not a direct action of the tool but the abrasive vibration caused by the ultra-sound's action.

Its speed is inferior to that of a grinder but the future looks more favorable. Finishing can be improved by diminishing the abrasive grain. Also several heads can be attached.

### VIII – 5 – 4 – Soldering plastic surgeries with ultra-sounds

In my opinion, this should replace our classical reparation techniques.

In fact, the transformation of mechanical energy into calorific energy is independent of the di-electrical qualities of material to be soldered which come into play when using classical means (high frequency). The ultrasound resolves this problem of independence so we have the possibility to weld materials with weak di-electrical loss such as plastic surgery.

As far as metals are concerned, the quality of this type of soldering should quickly replace all kinds of soldering.

VIII – 5 – 5 – Technical assistance

Let us simply say that the work of MARTY is sufficiently explicit. We will only note that the ultrasound application of classical milling frees us of many of the worries of precision milling (cutting, etc…) and the life of steel tools is much greater.

The benefits of high-frequency and low amplitude ultra-sounds during milling can be summarized as follows (MARTY):
- less residual tensions of hard metals
- better surface condition
- disappearance of returned ridges
- increased tissue life
- partial diminution of cutting efforts

So we should not hesitate to apply it in order to improve the quality of our work.

## VIII – 6 - SPECIFIC HIGH-ENERGY PROCESSES

VIII – 6 – 1 – Electronic bombardment

The goal is to concentrate a beam of electrons on a metal. The goals are diverse.

VIII – 6 – 1 – 1 – Theoretic principle

$W = \frac{1}{2}$ n $\quad\quad$ m $V^2$ = n e v

This formula is fairly well-known...without specifying the terms.
Among the means proposed we note:
- Barrel with high-tension acceleration
soldering and micro-milling
- Barrel with fine focalization and average fusion
- Barrel with transversal beam and multiple chambers:

Here we note focalization by form electrodes (see drawings n° 65 e, f, g).

### VIII – 6 – 2 – Applications

They are varied (milling, evaporation and annealing). In machining, we note the perforation of very fine holes, 50 to 25 µ long (drawing n° 65).

During metallization, metallic ions are projected. The advantage lies in the range of metals used and the fineness of a few microns. Also, it is possible to deposit layers of various materials during a single treatment, the effect is quick.

Annealing does not directly concern us.

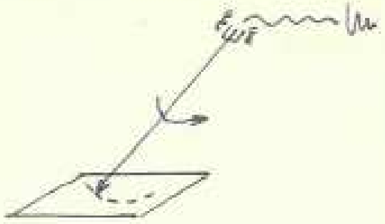
### VIII – 6 – 3 – Soldering

It is tied to a very important point that must be explored further. The upheaval is enormous in this area. It is possible to assemble metals whose fusion temperature and thermal conductibility are different. We are able to do this by directing the beam in a determined angle.

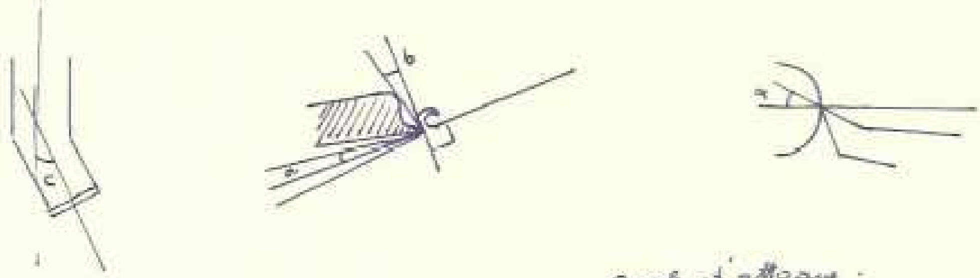
The weak heating and equally distributed tensions in the solder's thickness allow the use of soldering by electronic bombardment to repair complex and closed parts.

## VIII – 7 – LASER

The theoretical aspect was developed in depth in Chapter II so we will not remind its principle.

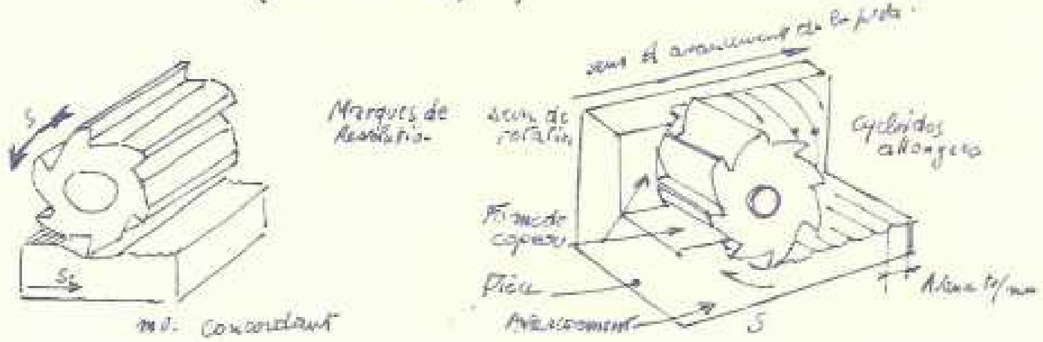


(dessin 66 a)



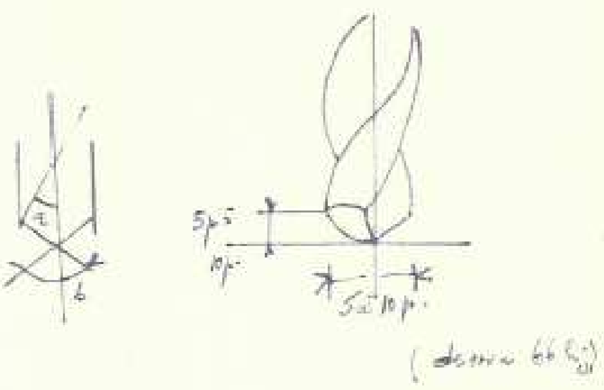
angle d'attaque

(dessin 66 b, c et d)

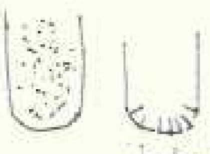



(dessin 66 e.f.)

(dessin 66 g)



(dessin 66 h, j)



instrument diamanté

(dessin 66 i)

VIII – 7 – 1 – Milling (drawing n° 66 a)

For us its role is essentially soldering and cutting. We can say that the soldering point has the advantage of presenting only a few microns so that after treatment and sculpture, we can solder with a similarity close to natural teeth.

The advantage of laser soldering is that it is done with precision, without deformation and even close to weak materials (ceramic) without overheating. There is no grain enlargement so almost no future risk of breakage for materials that are sensitive to growth of grains such as stellites.

Drilling allows trumpet-shaped holes which is not useful to us.

However, cutting does interest us. It allows us to replace the mask system (drawings n° 64 f, g). In fact, once the tracing has been done, the material deposited by the action of the laser beam can be cut without fear of structural modifications.

## VIII – 8 - MILLING

The representation of a traditional exploration is a cut which until now passed by the micro-palpitator measurement. The profile obtained would give displacement values of the palpitator on the X axis and on the Z axis (the X axis represents the space covered, the Z axis the height of the groove).

This was classic but limited because one usually assumes that the explored surface is uniform and that its texture is even which is not our case. Therefore, in a classical method by rectification with the grinder, throttle chamber, honing, iodizing, drilling at the end of the tooth, sandblasting and shot blasting, we did not have a marked profile direction. It was the same with defects coming from machined metals.

Many devices added the third dimension (micro-topographer) and scanned a 50 by 50 focus plane in successive parallel lines with a precision of 0.1 resulting in a very interesting surface representation.
Coupling with end milling presents the need for the three dimensions proposed by this device but the amount of time is too long in our opinion. Our scanning system seems more interesting to use and it provides the three dimensions.

### VIII – 8 – 1 – The problem

As we have seen, the problem that must be resolved is to obtain a variable volume, in other words, not a geometric value as a circle or a square, but a broken line.
There are two things in our action:
- the part
- the cutting tool

The part
For complete impressions it is either the gold ion type crown or preferably the electroform deposit or resins (ARALDITES).

The tool
It is the cutting part that will remove the excess material.

Several tools exist. Let us just say that in our case we foresee only a circular displacement of the tool and the machine turning principle that is to say, the part which turns around an attached or unattached blade.

### VIII – 8 – 2 – The tool

In this section of the chapter we assume that it is the tool which turns and not the part. The tool is made of steel (ordinary or special), cast iron (ordinary or special), stellites and diamond frittaged carbides.

VIII – 8 - 2 – 1 – Milling aptitude of the cutting tool

Before choosing the type of milling machine, the following factors must be considered:
- cutting pressure
- cutting temperature
(Energy needed to tear the shaving, to scrape the shaving and the metal on the tool, the conductibility coefficient and tool mass, the conduction coefficient, the mass and surface of the part to be milled).
- wear of the tool
important factor

For this, we propose a trimming followed by finish in various steps which avoids the tool to wear out too rapidly.
- shaving formation
- surface condition

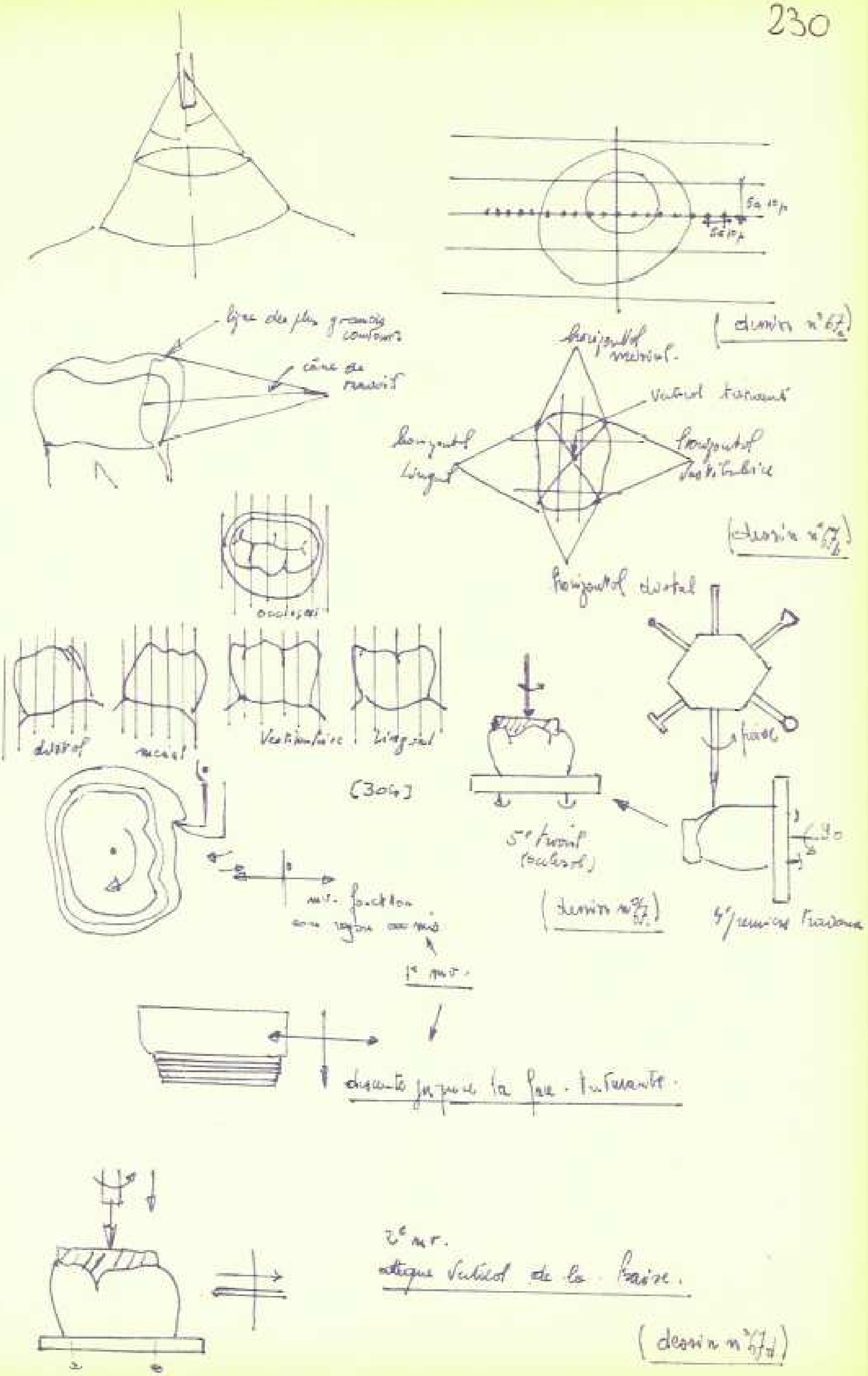
VIII – 8 - 2 – 2 – The tool's characteristics

- angle of no retention, grinding slope and direction (see drawings n° 66 b and c).

The studied shaving will offer a choice of these tool angles. From this choice we will determine their value according to the metal we will work on (continuous or discontinuous shavings).

The build-up edge is the accumulation of shavings which leans against the instrument (and tends to push it back). We must therefore find the minimum shaving size.

It is clear that the worked metal and the cut influence:
- the cutting pressure:



ligne des plus grands contours
cône de travail
horizontal mesial
vertical tournant
horizontal lingual
horizontal vestibulaire
(dessin n°67a)
(dessin n°67b)
horizontal distal
occlusal
distal
mesial
vestibulaire
lingual
[304]
5e temps (occlusal)
(dessin n°67c)
fraise
1er mvt.
descente jusqu'à la face triturante.
2e mvt.
attaque verticale de la fraise.
(dessin n°67d)

= cutting condition – front view
= section of the shaving
= depends on the nature of the worked metal

## VIII - 8 – 2 – 3 – Influence of the cut

The factors are:
- the worked matter
- the slope of the tool (pressure decreases if the slope increases) (see drawing n° 66 d)
- the ideal direction angle is 90°
- lubrication allows increased production per time unit
reduces scraping work
lessens the power by cleaning
- allows an increase in speed
- allows an increase in the supply of material

When we go from dry to moist work, the cutting speed must be increased. The better quality of the lubricant, the higher the speed.
-wear
Variations in metal, speed and lubrication are determined automatically if a wear table is established.

## VIII – 8 – 2 – 4 – Milling machines

Milling machines are revolving solids with tools called cogs located on their circumference in equal intervals which adjust themselves intermittently in the part to be milled.

The movement of the milling cog and the part can be in opposition or in concordance (“eating up”) (see drawing n° 66 c).

Various forms of milling machines and various ridges’ form can be used. Work can be perpendicular or parallel to the part (see drawing n° 66 f). In our case, both will be used at the same time (see drawing n° 66 c).

The choice of the milling machine will be made according to experience. The limit of the action and precision are linked: the finer the milling machine the more gently it turns and the speed at the center will be null (see drawing n° 66 g).
In order to have a precision of 5 to 10 µ, the given measurements must be balanced (see drawing n° 66 h).
The angle must be given in point (a) and the helix in degrees (b) (drawing n° 66 i).

A good solution is to cut with a diamond tool with or without facets. Its precision can be increased according to the fineness of the grain. Also, the diamond is one of the hardest materials (drawing n° 66 j).

### VIII – 8 – 3 – Our utilization

The work will be done by successive lines corresponding to the scanning and done by the analyzer tube.

A surface will thus be reduced in a succession of parallel lines whose spacing will correspond to the device precision.

The milling machine's work axis will be single where there is one clearance cut and multiple if counter-clearances exist.

#### VIII – 8 – 3 – 1 – Case of a stump

It is the classical non retention.
The part, an impression of the stump was carved in a chosen material. The work axis and the finished stump will be the bisecting line at the top of the cone. Therefore, the complete front side will be accessible to the tool (drawing n° 67 a).

#### VIII – 8 – 3 – 2 – Case of a crown impression

It is the case of the counter-clearance.
We either orient the milling machine or the axis in different angles in order to sculpt all the details.

Drawing n° 67 b explains the proposed idea which can be modified if necessary but this counter-clearance can be obtained anyway (drawing n° 67 c).

Thus we see that a tooth divides itself into 5 characteristic sculpting planes, by 5 lines of greatest contour…by 4 horizontal work axes (vestibular, lingual, distal, mesial) and 1 vertical axis (occlusal).

Considering the possible angle of scanning the holographic plate, we can obtain 5 sides.

The 5 sides will be sculpted separately and the whole will form the complete tooth.

The simplest tool appears to be one that is fixed in one direction with a variable milling machine but base of the impression turning at 90°, 4 times in the occlusal plane and once at 90° in the sagital or frontal plane of the tooth.

The computer's only function here would be to induce the instrument's action until the point of greatest contour.

We can sculpt any surface following this same process.

### VIII – 8 – 3 – 3 – Turning

We could perfectly accept a sculpture to replace the horizontal one. This would allow us to imagine a work device, first as a turning that makes a horizontal head work then by driving a milling machine for the horizontal triturant carving.

The advantage of this system would be the execution speed which is perhaps the solution.

The impression would be a succession of circumferences spaced from 5 to 10 μ.
The part would turn from top to bottom or inversely, from the flange to the triturant surface. Once arrived at this surface, the milling machine head would only work on the triturant side (drawing n° 67 d).

## VIII – 9 – CONCLUSION

### VIII – 9 – 1 – Comparative study [BEZIER]

#### VIII – 9 – 1 – 1 – Classical machine

Classical machine tools quite easily create movements of rectilinear translation and rotation (milling) and generate good precision.

These classical machines act either by movement of the milling machine or by displacement of a carriage (milling machine with crossed carriage).

In order to satisfy the precision we have added brain-mechanisms. Machines working by abrasion show rectifiers that function with the help of a gauge or by optical comparison of an outline with the profile of the part.

Except for cylindrical cones rectifiers, contact between the tool and the surface to be generated is punctual and not linear. If the advance is very weak, the grooves left by the tool are practically imperceptible but in the contrary case (milling) the excess must be removed.

Milling machines work under fairly mediocre conditions especially where high precision is concerned.

#### VIII – 9 – 1 – 2 – Recent processes

We will not dwell on this because we have already seen it in detail. Let us just say that, for many reasons, processes such as electro-erosion are the future.

The choice for us remains to be made and this choice is function of what we require from our machine tool (electro-erosion can give ndercuts).

## VIII – 9 – 2 – Conclusion

In conclusion we can say that any metal (available to us) can be modelled or sculpted with a precision of 50 µ for sure and from 5 to 10 µ with very fine processes.

Machining therefore allows very closely the precision of the optical impression.
We will now relate our study (from the beginning to the end) to our profession.

# SUMMARY AND APPLICATIONS OF THIS IDEA TO OUR PROFESSION

- ESTABLISHED CORRELATION
- OUR WORK IN THE DENTAL PRACTICE

# CHAPTER – IX-

## INTRODUCTION

We have explained in previous chapters how we could base ourselves on truly existing techniques. Each step is achievable; computers have been created in various fields.
All we have to do is to recall them in order to link them to our profession with regards to this study.
Finally, we will explain a potential opening towards other areas.

## IX – 1 - ESTABLISHED CORRELATIONS

There currently is a reading system or holographic TV; this means that devices taking an image in three dimensions then analyzing it (convertors) have been perfected. The computer liaison (analogical, numerical convertor, computer) also exists. The numerical command of a machine tool and sculpture are tied. We can say that our goal is to link the various phases considering that this already exists in other fields and to draw from it what applies to our profession. The holographic TV scanning must be linked to the computer, i.e. perfect a program and then create a command program chosing our machine tool (see drawing n° 68 a).

Our role will be to link these techniques, to orientate research on these links and to coordinate each specialist in his own phase.

## IX – 2 - OUR WORK IN THE DENTAL PRACTICE

Several cases can be foreseen
- the tooth is either healthy (crown on a living tooth)
- or it is ruined or even missing

If it is healthy the computer is useless. All that needs to be done is to take the optical impression before cutting then after the cutting.

In the other case, the computer is necessary. We will obviously discuss this case further.

### IX – 2 - 1 – Preparation

Whatever the goal to be attained, the quality of our work (cutting) is in no way changed; it must only tend towards improvement (removal prosthesis, fixed prosthesis).
However, in surgery the impression is done before opening so there is no blood.

### IX – 2 - 2 – Verification

The change begins here. Normally once the cutting is done we do an impression after having verified with the probe and the magnifying glass. This method is quite imprecise in our opinion. To lessen the imprecision, we propose to take a hologram of our cutting and to enlarge it in order to see the details better.

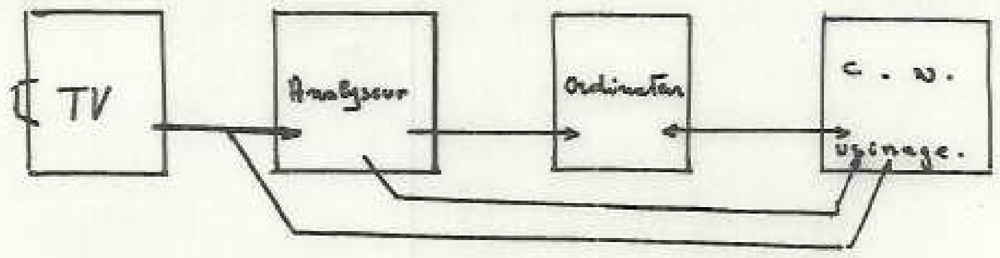
#### IX – 2- 2 -1 – Taking the classic hologram

We place our laser, for example Helium-Neon, at the entrance of the mouth where we bring the beam using fiber optics (see additional information).
In order to have good lighting we take the interferences on a plate or a soft fiber in a few seconds. We can take 150 views on the same film by changing some of the device's parameters.

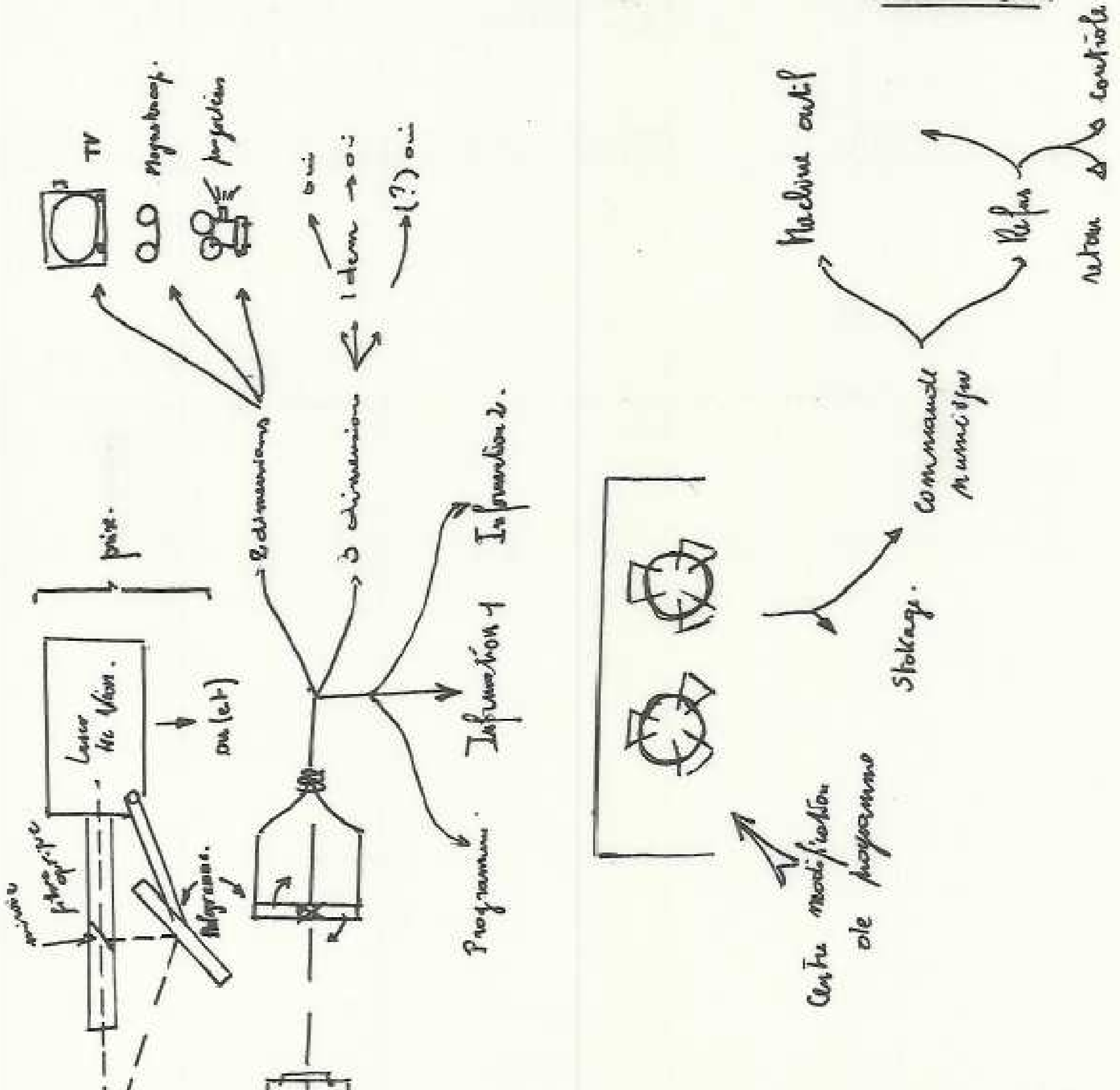
Once the hologram is done, we set it on an analyzer base that allows us to reproduce the impression's image using the same laser (see Chapter IV).

We can also cancel the plate and use the eye of a holographic camera (see Chapter V).

In both cases we record the information on a video recorder if so desired (drawing n° 68 b).




(dessin 68a)




(dessin 68b)

Schéma général.

The analysis of the plate can be done with the eye but also by projection on a TV convertor tube in three dimensions (holographic TV). When a lens to enlarge in three dimensions is found, it will become possible to increase the relation of the virtual and real object beyond 1/1 and even to do a projection on a cinema screen.

From now on if we want to verify roughly the enlargement of our impression, all we have to do is project it on a large cinema screen located in a dental practice and our 3m/3 stump can be seen.
The hologram's analysis in real time is done from the three-dimensional impression reduced twice or by rotating a secondary camera (see drawing n° 69 a). A progressive study of the hologram at 180° is projected in two dimensions so we progressively see all the sides of the tooth. The method of the divergent beam estimating the depth of field can be used (see drawing n° 69 b).

#### IX – 2-2-2 – Conclusion

The cutting will be verified and enlarged so that there is less fatigue for the eye and more precision. Finally we move outside the mouth what was left until now, the evolution of our work and the observation of the cutting before the impression was done.

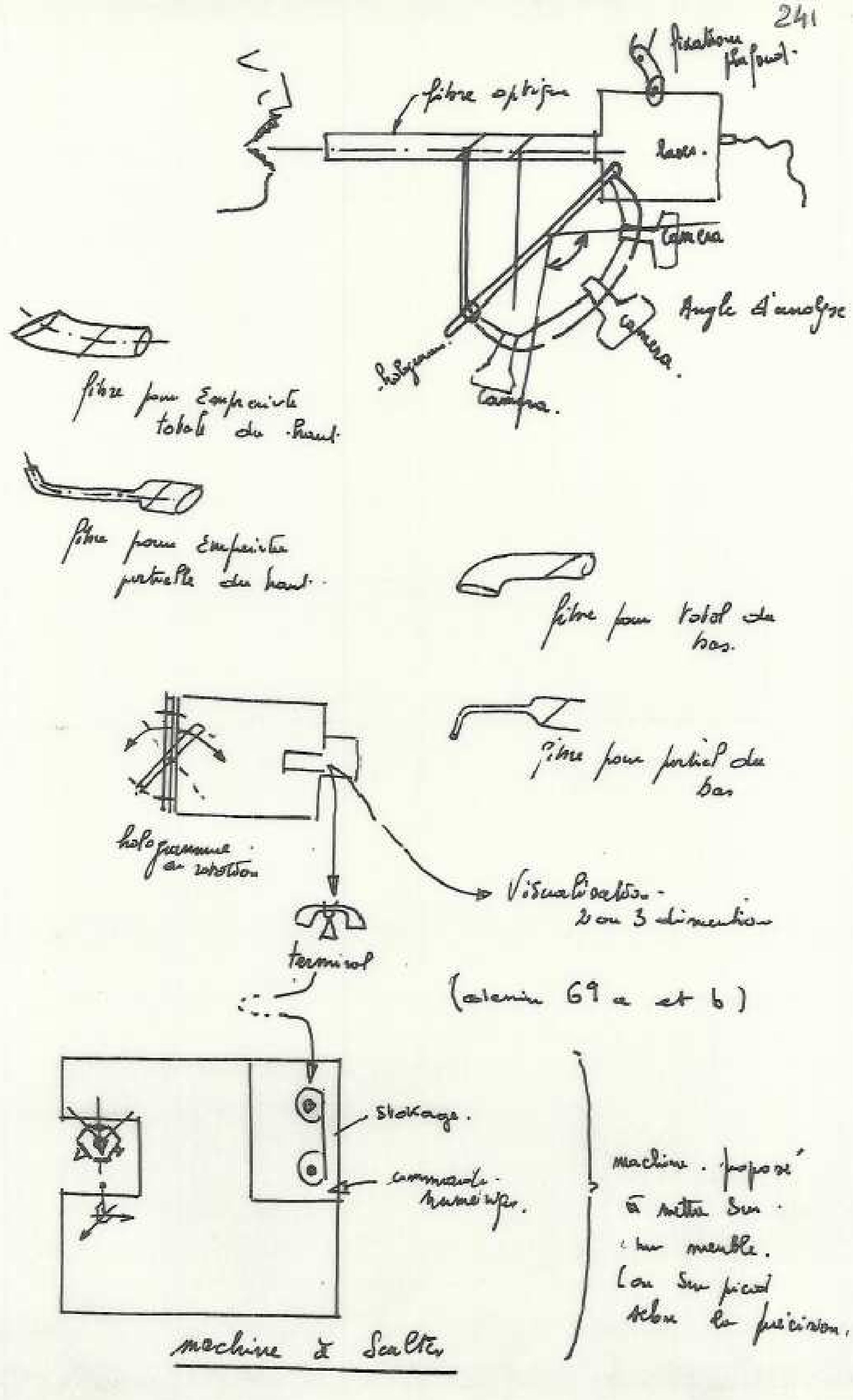
We could project the various phases of a job by recording during the execution in real time (film) or in deffered time (plate : by analysis of a hologram having 150 successive views "on a video recorder" (see Chapters IV and V).

### IX – 2-3- Study in depth

#### IX – 2-3-1- Classical repeated optical impression

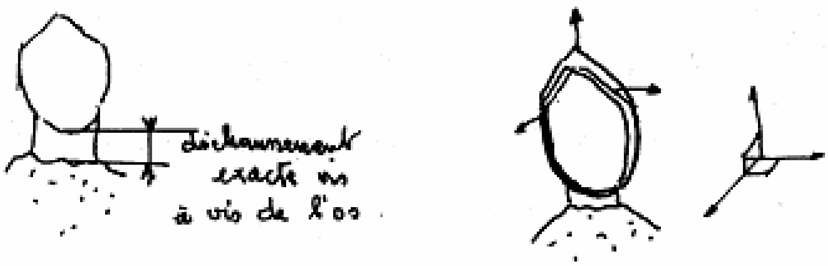
a) in daily practice

The evolution of esthetics of the mouth can be justified to a patient (less cost: real time).


241
fixation plafond.
fibre optique
laser.
camera
Angle d'analyse
camera.
camera.
hologramme.
fibre pour Empreinte totale du haut.
fibre pour Empreinte partielle du haut.
fibre pour total du bas.
fibre pour partiel du bas
hologramme à rotation
Visualisation 2 ou 3 dimension
terminal
(dessin 69 a et b)
stockage.
commande numérique.
machine posée à mettre sur un meuble. (ou sur pied selon la précision.
machine à sculpter

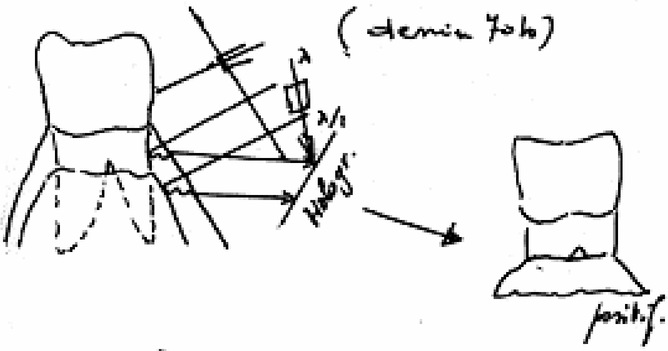

(dessin 70a)

## orthodontie



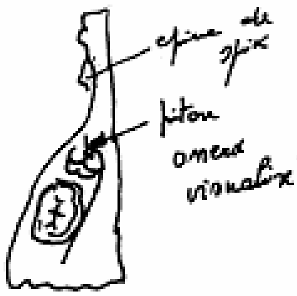

(dessin 70b)

## Parodontologie




(70c.)

(dessin 70d)




(dessin 70e)

The choice or defect of a project can also be demonstrated to colleagues or prosthesists.

In orthodontia we can visualize if we have a progression, a version or any other local or general movement [by successive optical impressions at each session, the whole resulting in an animated drawing (see drawing n° 70 a)].

We slightly vary ʌ in order to see this movement and each view is superposed by photographic recording.
In parodontology a dental movement can be visualized by impressions in real time and by the precision of the wavelength and even by a non-bleeding method, find the exact value of any receding gums (see drawing n° 70 b).
b) <u>in research</u>

Double purpose, teaching and research.
In teaching, recording a project will be obvious and simple, the technique if it is used will allow to record the evolution of the work and immediately project on a screen these successive optical impressions.

In research we can store our ideas and return to them even 30 years later.
No technique will die.

<u>c) general</u>

As in applied science, any object can be reproduced without a prior double matrix and without the fastidious use of the micropalpitator.

Thus we can create models of what we observe, on the microscope: visualization in three dimensions that can be touched or reproduction of rare pieces which can be kept.
It is the three-dimensional photocopy.

So any piece can be reproduced directly or by telephone from a museum to any individual who owns this device (direct telex impression). In the same way, by superposing holographic impressions, with a base one can file parts even though they differ, as long as their characters are accurate.

FOURIER's transformation transposes the geometric representation by variables x and y in a series of spatial frequencies f (x, y). Three properties show the interest in this in the resemblance of forms.

1°/ - Formation of a function in FOURIER's terms introducing only one single parameter, the spatial frequency whatever the considered function of the object.

2°/ - The lower frequencies translate the continuity, in other words, the uniformity of objects whereas the fine details (contours, discontinuity points) characteristic of gaps between forms correspond to high frequencies that spread themselves on the edges of the spectrums.

3°/ - Writing, in FOURIER's terms, of any function is done on a continuous basis, as in the case of the geometric space. This allows optical comparisons of forms even when there are intermediate forms of continuous chains.

In chemistry, we can visualize huge molecules… or smaller ones later. Nothing proves that we will not sculpt unobservable things when working on $\lambda$ of around 1 Å (the eye becomes useless if we increase what the machine observes).

Finally…if "Apollo" has this device on board and matrixes of defective pieces, nothing prevents the information to be sent in order …but this is a dream ! The purpose of this part of the thesis is to recall the innumerable application possibilities.
In any cases, suppressing the piece would allow by preparation the reproduction on paper of ideal theoretical parts and to cancel many manipulations (see "Le travail en miettes" by FRIEDMANN).

IX – 2-3-2- Secondary optical impression

(see Chapter III)

IX – 2-3-2-1- Surgery - Impression

a) simple visualization

The principle is such that the reflection in an environment is a function of its index n (of its coloration, see Chapter III). Such an idea is not proved (but comes only from our imagination, so it might not be realizable).
However, everything leads us to believe that a study in this sense would prove precise.

In Chapter III we insisted on two things: tissues absorb or reject and even transform certain wavelengths during their passage. Following this “observation” nothing prevents us from stating that an in-depth study of these characters would tell us which parameters (I $\lambda$) represent a reflection on the bone and on melanocytes and which frequency is needed to obtain interference at the output after reflection.

Knowing the output frequency after reflection on the bone and by causing an interference with this frequency on the plate, only the rays reflected by the bones are stored. The impression obtained will be the bone’s one (invisible) and not the gum’s (see drawing n° 70 c).
We call this impression the “secondary optical impression”.

b) coloration

In the same way by electively coloring the desired observed zones, we can obtain reflection and elective interference of these zones, thus a visualization which is itself elective (see drawing n° 70 d).

IX – 2-3-2-2- Application

a) Enclosed teeth

Visualization of the tooth will allow knowing:

- its position in space and time
- its relations (see drawing n° 70 e)
- distinguish the bone point to remove

b) Maxillary fracture or other fractures

A fracture line, the displacement of a piece of bone in space (wrench) is visualized by this impression (see drawing n° 71 a and b).
Its replacement will be even more precise.

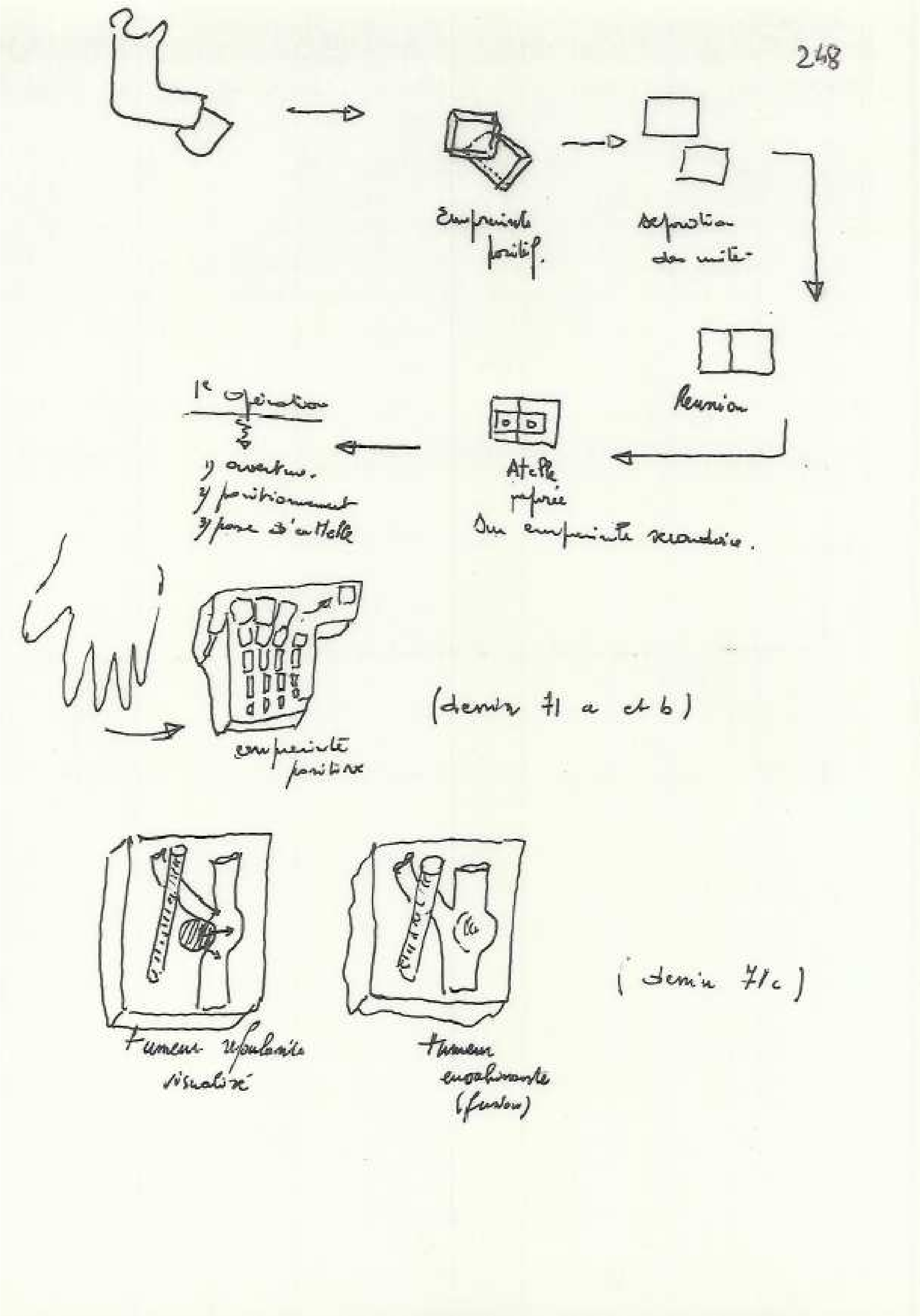
c) Tumors and anatomical relations

An elective coloration (Chapter III) together with a change of parameters of the ray enable us to locate a tumor, its relations or any anatomical part. The essential interest of this method is:

- the ability to know if the relations are being suppressed or if there is an invasion, in other words, the kind of tumor
- the ability to visualize the venous or nervous relations, thus greatly facilitating certain operations that are difficult to approach (neck), thus we can locate the tumor or any other malformations and, by means of these relations, choose the access to follow without risk of dangerous lesions (see drawing n° 71 c).

d) All kinds of bone splints

High-surgery, in bone surgery the impression of a bone can be pefectly acceptable followed by the preparation of the retention splint before opening the leg.
The advantage is that the prosthetic piece is prepared calmly with good materials and without bleeding methods and the bone pieces can be joined in ideal position. The metallic piece is not pinned until the bone pieces are joined perfectly. The ideal would be to know the anterior position. We propose the same type of applications which are often idealistic but achievable (see drawing n° 71 a  BRUGIRARD).


248
Empreinte positif.
séparation des moitiés.
Réunion
Attelle préparée
sur empreinte secondaire.
1e opération
1) ouverture.
2) positionnement
3) pose d'attelle
empreinte positive
(dessin 71 a et b)
Tumeur visualisée
Tumeur envahissante (fusion)
(dessin 71c)

- Anatomy: the bone aspect for a given individual can be precisely visualized without bleeding methods.
In our profession we can also see, for instance, the Spix spine, the chin hole or the palate holes…

e) Implantology: dual aspect

1°/ An impression of the alveolus enables to obtain an exact positive of the alveolus and thus the position of a tooth in porcelain or in ideal metal.
2°/ “Plate” implants will be made easily and precisely and ideally placed (see anatomy and surgical splints).

f) Fixed prosthesis (see drawing n° 72 a)

The secondary-type impression lets us consider the impression in two relations: the tooth and its base.

- The base: it is the bone. We can see its appearance and its texture, the degree of receding gums, the unevenness.

- The tooth: it is the only strict impression allowing to visualize absolutely without wire or other traumatizing methods the carving of the triturating edge at the edge of the bone (and not at the collar). The problem of epithelial attachement must still be resolved.

g) Removable prosthesis
The wave that can be obtained may, in our opinion through a judicious choice and considering the equivalent parameters, take an impression without pressure, successive in time (primary impression). The successive impression does not allow us to modify the circumference of a paste (very aleatory) but to progressively eliminate contraction zones from the theoretical cutting. Thus through selected movements added to an extensiometric palpitator, we can locate the ideal circumference on the computer (see drawing n° 72 a).

From the difference between the primary and secondary optical impressions we have the exact thickness of the epithelium…. It remains only to deduct precisely the pressure zones or not (see drawing n° 72 b).

For the skeletal prosthesis we will use the ordinal program.

h) Working with metal

Working with metal is an important theorical problem in practice : the constraints in metal can be visualized in "coherent" interferometry as well as in classical interferometry. The practical result is that our recording device allows us to visualize effort zones in the metal by means of such an impression (see drawing n° 72 c).

i) Verification

Superpositioning the theoretical hologram and the crown permits [77] to control the preciseness but also with time, the degree and the wear position. Thus, in paradontology we can visualize the wear zones and their evolution. This idea is applicable to natural teeth (see drawing n° 72 d).

### IX – 2-3-3- Conclusion

Whether the primary or secondary impression is concerned, the result is very interesting. The research center should further study the parameters (…and coloration) to take full advantages of this method.

It would not be interesting if the method were to stop with the sculpting of an impression. Our goal is to go beyond the impression, to research as many practical applications as possible because this method resolves many other problems.

j) Problem of the post and the fractured instrument

As we know, the problem of the post is essential. We believe that since it is possible to take any detail of the tooth, we can take the impression of the post and, in the same way, of the canal. If this is not feasible, the impression will be done with the post in place.
If it is possible, the post will be placed after the impression is cast or even sculpted according to the exact impression of the canal (suppression of the mooser).

In the same way, if we can take a canal, we can take an impression of the pulp chamber. It seems obvious, therefore, that the impression takes on another dimension.

1°/ - Second degree

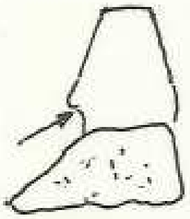
The second degree impression allows the creation of the inlay, perfect onlays. Thus the amalgam becomes useless and the cement will be replaced by sealed porcelain. The era of the “filling amalgam is almost at an end”.

2°/ - Third degree – simple

The cavity is visualized by an impression. Therefore, the orifice can be visualized which allows customized capping.

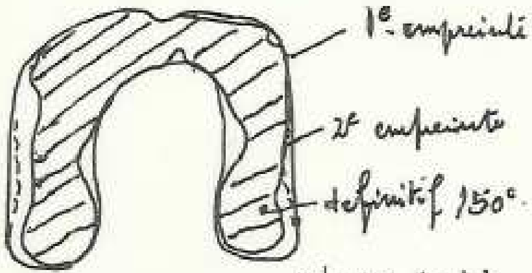
3°/ - Third degree - complex

Visualization by impression outside the mouth would allow the removal of the roots and would let us know if the tooth is correctly open (suppression of the pulp cusps). Then we can indicate the placement of canal instruments or a potential fusion of the roots
(see drawing n° 72 e). Finally silver cones would be tailor-made through techniques that have yet to be developed.



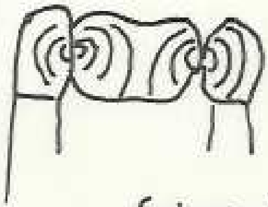
(dessin 72a)

visualisation d'une contre dépouille



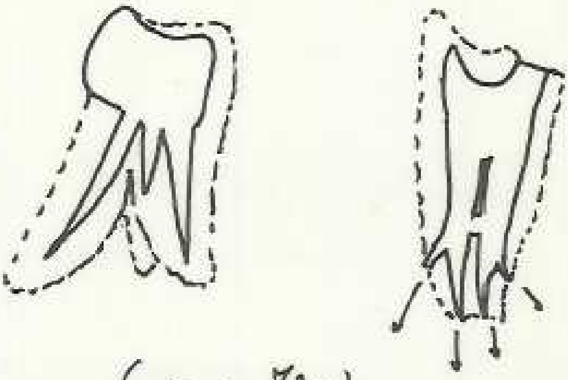

(dessin 70b)

prothèse du bas.

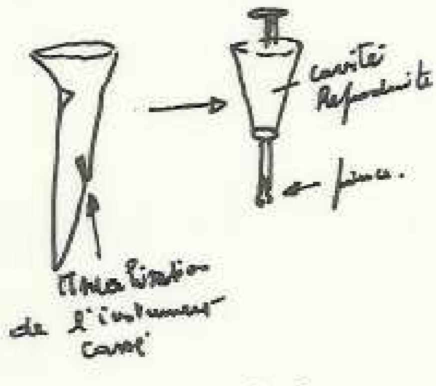


(dessin 72c)

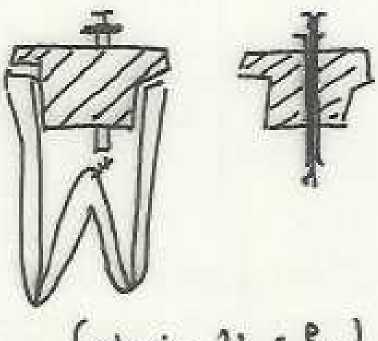

(dessin 72d)



(dessin 72e)




(dessin 72f)



(dessin 72 g h.)


(dessin 72i)

In case of instrumental rupture

The fragment will be identified and the instrument for reaching it will be prepared carefully, for this a transparent araldite will be used (see drawing n° 72 g). Instruments with one piece and a hook at the end will be available (see drawing n° 72 f) upon which we can cast a precise impression of the cavity in degradable araldite (see drawing n° 72 g).
The instrument will just have to be introduced, the hook placed exactly on the broken piece, as araldite and cavity are complementary and the extraction is done immediately (see drawing n° 72 h).
Let's mention that the application would allow moving research to another area: a more extensive choice of metals. By this method they can be cast as well as worked on directly.
Finally, a broken root will be displayed rigorously without risk of artifact (see drawing n° 72 i).

IX – 2 - 4- Analysis of numerical data

The impression's analysis is recorded by the hologram then analyzed by scanning or any other technique.
Thus we can state that scanning data come progressively.

IX – 2 - 4-1- Receiving information (see Chapter III and V)

IX – 2- 4-1-1- Video recorder

Recording on a video recorder is done by magnetic impulses resulting from intensities from ponctiform analysis of the image.

Restitution can be immediate and can drive the numerical command of a machine tool.
This same restitution forms the beginning of a constitution in an image of the impression. Following the data, it is possible to sculpt the interior of a crown. This does not require a computer.

Finally if the crown is alive, we will first have the impression of the tooth as it should appear after.
The problem that arises is obviously the space that must be left for the cement or the diminution of the “cusps intensity” according to the metal used for the crown (according to some accepted theories). To resolve these problems, we will use the computer.
The video recorder allows a dentist to store in his practice tapes that have data in all their forms.

**IX – 2-4-1-2- Television, cinema projector**

These allow us to visualize in the dental practice as in research centers (see below) the impression in order to control the requirements.

**IX – 2-4-1-3- Terminal**

Data retrieved on the “optical impression” must be transmitted in the second degree of work to a computer to have larger treatment whether it concerns primary or secondary data.

It is unusual to own one’s computer. We propose the use of a computer that will be connected to each offfice by a telephone-type terminal for example.
Data will be sent by this means to the treatment.

IX – 2-4-2- Computer (Chapter VII)

IX – 2-4-2-1- Reminder

Remember (see Chapter VI) that the computer is schematically the machine capable of accepting data in coded form, of applying certain transformations to them and to produce results in coded form.

We will have two kinds of information:

- Information 1 will be a tooth or n typical teeth of the mouth that we will analyze.
This means that the computer will receive the optical impression of a more or less worn tooth according to age, physical condition, etc…

- Information 2 will be the optical impression of the stump or the cavity, for example, that we want to treat.

The program will be the factors that will intervene so that the crown, the device or any other piece will be ideally reproduced during sculpting.

The dentist must transmit these two types of information as well as the type of program selected.

For example, for a gold crown he will transmit :
1°/ - information 1 : 6 4 7

2°/ - program C    C R Gold
8
- program C'    {antagonist gold
{
accessory    {1 m/m receding gums

3°/ - information 2    average of 8

In the chapter on computers we developed the ideas further but we should note the simplicity of use. The data only has to be transmitted and the type of the desired sculpture chosen from established tables.

In this same vein, the data transmitted for a skeletal device would be :
1°/ - program G Sq Gold
{6 teeth…
{respective mobility
{root lengths
{according to DUBECQ and CUMMER

2°/ - impression data

## IX – 2-4-2-2- Research center

To establish a program we believe the computer should be in a research center. We mean by this that researchers specialized in each area will create and modify their programs according to their own research but also according to results obtained in dental practices. Thus no practioner would be isolated in his work and basic recycling would only be partially necessary. Only the specialists would change certain data in order to obtain ideal crowns.

For example, sculpting a skeletal prosthesis would be done using theories that follow the evolution of research. A modified 74 DUBECQ-type program could be selected by the dentist.
In orthodontia data would follow the evolution of this science.

## IX – 2-4-2-3- Advantages of the computer

Sculpting (of the crown obviously) would be modified according to the desired metals, anatagonists, degree of latent wear of the mouth in question, and the latest theories…

Three kinds of sculpting will be proposed (see drawing n° 73 a).

- First is the impression

- Second, the interior of the crown which increases according to the granulometry of the sealing cement.

The granulometry could be modified without affecting the precision of the whole in order to allow worry-free, ideal insertion of bridges (see drawing n° 73 b).

Regarding the stump :
If the stump is normal and the insertion possible (considering the elasticity of the metal), the interior impression will be intact.

If, on the contrary (see drawing n° 73 c), the counter-relief (for example) is too large, two solutions are possible:

- information refused considering the percentage and admissible error;
- approval and interior shaping with ideal modification considering the bad cutting of a crown, adapting perfectly to the tooth and partially to the accepted ideal.

This way the dentist will be warned in this case and will choose one solution or the other (see drawing n° 73 d).

The third sculpture

This will be the exterior sculpting upon which almost all the programs created in the computer will come into play. This is the exterior and anatomical appearance of the crown tooth.

Thus in addition to the impression, the computer will induce the sculpture of the crown or of any other prosthetic piece according to the chosen program.

The advantage of the computer is that it permits sculpting of the exterior of the crown by the same method as the one for sculpting the impression's positive. The program is made up of the data transmitted to the computer.

The third sculpting will also be the important modification of this program considering the theoretical but also the practical data.

Finally the large memory capacity that computer have permits storage of all the theoretical teeth of the organism (see drawing n° 73 e).

## IX – 2-4-2-4- Returning the computer information

The computer sends back three data of three positives to the numerical command.
This is done in codes intended for the sculpting.

IX – 2-5- Milling [300 – 301]

A - Single or total impression

IX – 2-5-1- (Re)milling

IX – 2-5-1-1-

This concerns sculpting a positive.
The machine is used directly without involving a factor in the program.
Information 2 [impressions] is transmitted on a block that will be sculpted. This block can be made of very hard resin such as araldite, a very hard metal or simply plaster.

We will take from this either the classic impression or the impression (surgery) of the bone, the veins with coloration of all anatomical relations.

IX – 2-5-1-2- The milling used will be :

If it is a metal conductor for example :
- electro-erosion
- electro-chemistry

if it is araldite
- milling
- ultrasound

a) Electro-erosion (see drawing n° 74 a)

1°/ Generator with impulsions (iso-energetic current)
2°/ Very thin cylindrical electrode 4 to 8 µ
3°/ The axis of the electrode-carrying piston will be in relation to the part, the one that the analyzer tube has in relation to the impression.
4°/ The number of the “electrode” piece can be 8 for example (considering the intensity) for an electrode with a width of 8 µ, 100 ups and downs and a shift of 2 mm will be sufficient to obtain a precision of 10 µ.

Results : Very good finishing (polish)
Relatively reduced time
Little wear on the piece
Very good precision
(to put in the program)

b) Electro-chemistry

1°/ Faraday's Law : M = Cste It
2°/ We will try for the same arrangement as in electro-erosion (micro-electrode, eight in number, width as necessary, displacement according to precision)
3°/ Considering the factors (824) and varying I, Faraday's law allows not only to reduce the finishing that is still very good but also to increase the work speed.

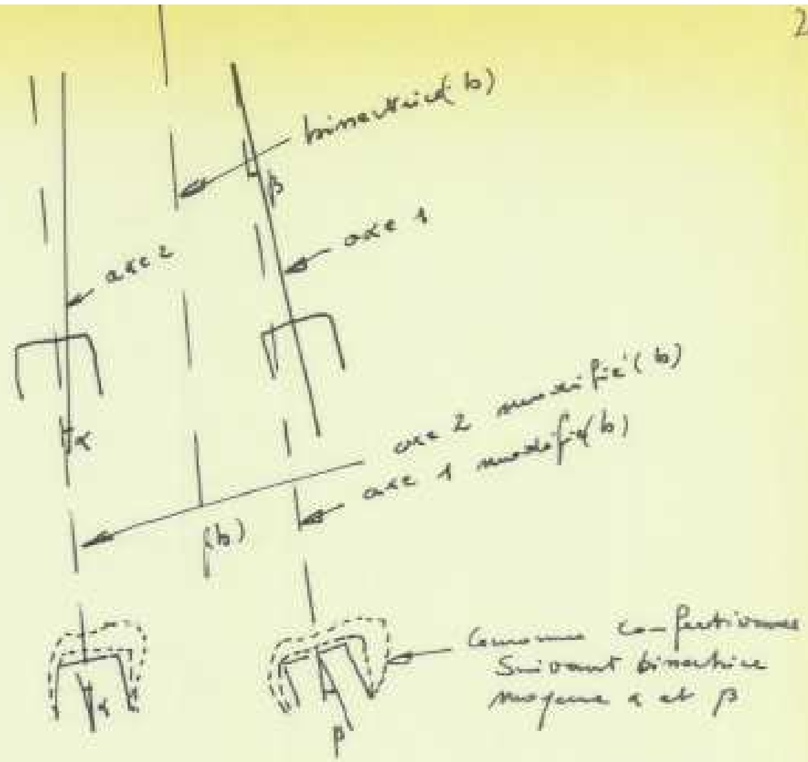
Advantages : - No wear on the work tool
- High precision
- Finishing and speed

c) Ultra-sound

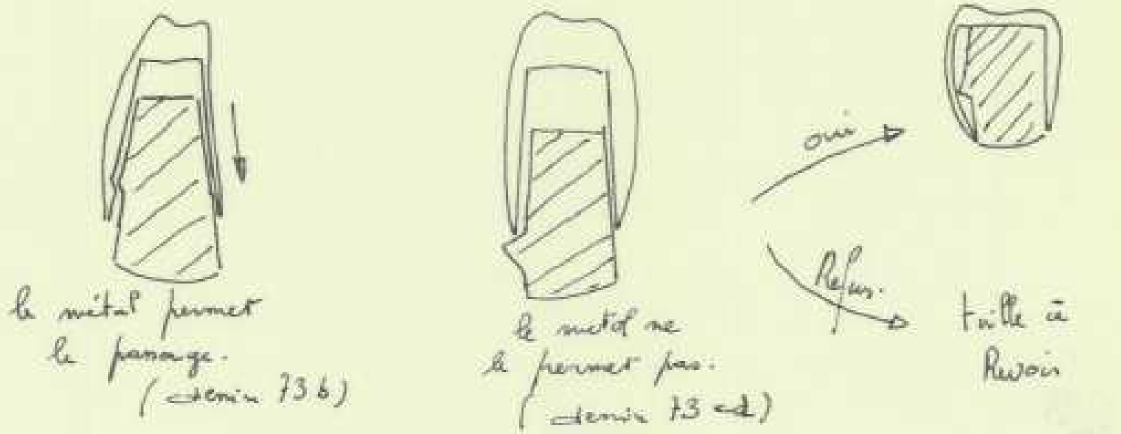
We will use a very thin blade that transmits vibrations. The granulometry of the abrasive is chosen according to the desired precision. Here again, we can accept scanning of the surface.

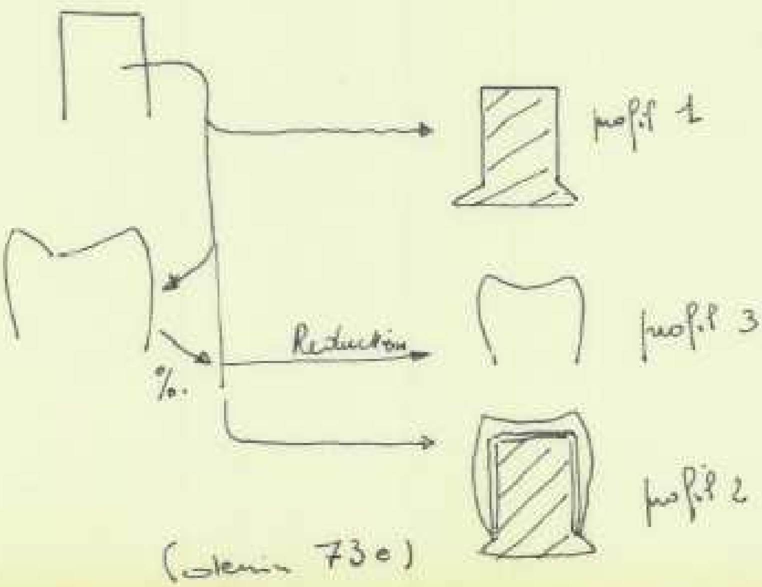
d) Milling (see drawing 74 a)

This work is always done in three dimensions. The problem will be wear on the piece. This wear must be reduced as much as possible giving the tool the possibility of working with maximum efficiency.
Obviously the approach from other angles will be reduced to obtain undercuts.




(dessin 73 a)




(dessin 73 e)

IX – 2-5-2- Presentation

If the impression is taken perpendicularly to the axis, or if this perpendicular is re-established and is perfectly clear, there is no problem: a work axis will be enough, the perpendicular axis to the impression's plan (see drawing n° 76 a).

However if the impression is in counter-clearance, the hologram will be analyzed according to two angles, even a scanning. The tool's approach angle will be the reading's one.

IX – 2-5-3- Result ( see drawing n° 76 b)

The result is a total or partial impression such as the one we obtain typically but what is not so typical is that the time is reduced up to 10 times. The impression can be made of stainless steel or in plaster, its precision will be what we want and not just what is possible. It will not vary in time and can be reproduced in n copies without affecting its precision.

IX – 2-5-4- Variations

IX – 2-5-4-1- Change of the instrument (see drawing 74 c)

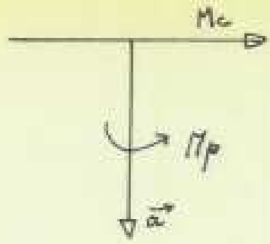
Other than its angle, a tool can choose its form which means that we can make sketches in milling, quick sketches then finishing by an electro-chemical process.

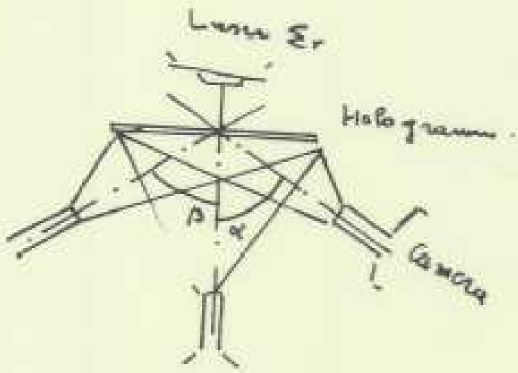
IX – 2-5-4-2- Change of the angle (see drawing 74 a and d)

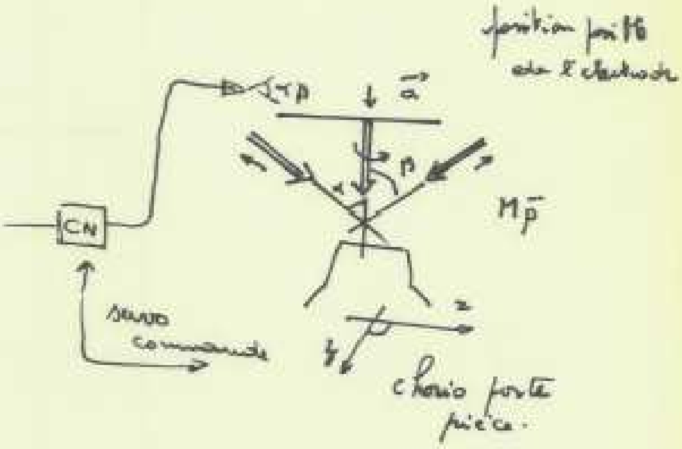
A counter-clearance (drawing) can deliberately be cancelled and obtain (II). Therefore the crown at the collar will be perfect because obviously the maximum diameter at the collar will be sculpted. All it takes is to refuse the angles α and β and to work only perpendicularly.

IX – 2-5-4-3- Change of the material

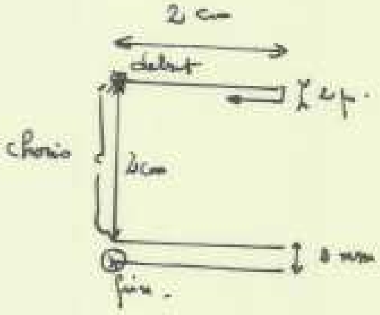
Obviously the work of resin products is less "traumatizing" and faster for a milling machine, but finishing remains delicate because it is impossible to use the electrolytic method.



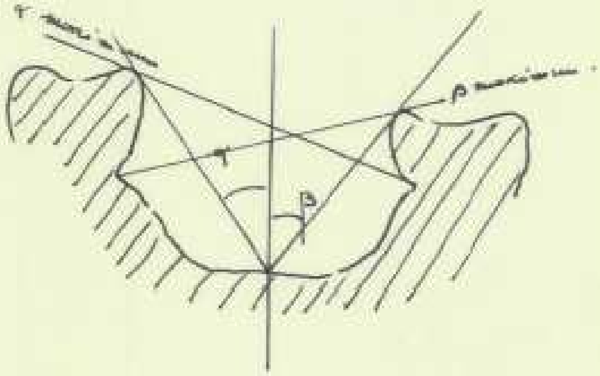



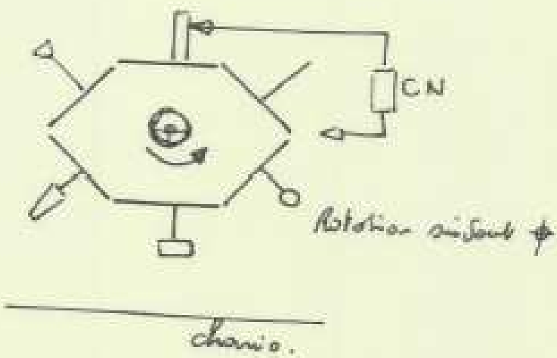




(dessin 74a)




(dessin 74b)




(dessin 74c)


(dessin 74d)

We will choose products for impressions so a finishing precision will not be necessary (D.F.O., parodontology, oral surgery).

However we can use very hard materials that allow us to cast gold in fusion (correction of the retraction is done mathematically) and consider a triturate inlay as a gold crucible…

By combining a hard but destructible material we can make a punch that we can destroy if, for example, the counter-clearance becomes necessary (see drawing 75 a).

Finally, we can put a very thin conductive deposit (silver) on araldite allowing us to treat the “resinous” impression for an electro-forming deposit, if necessary.

### IX – 2-5-4-4- Change of instruments’ shape

The angle and especially the approach shape of an instrument are such that we will have to study some sort of instrument for a precise utilization (drawing 75 b). A small counter-clearance can be obtained from a round milling machine or a reversed cone (see drawing 75 b).

### IX – 2-5-4-5- Factors (see drawing 74 top of page)

We have studied the main factors but it is important to note that other factors play a role
(rotation speed $\overrightarrow{Mc}$ , penetration speed $\vec{d}$, advanced speed $\overrightarrow{Mp}$).

### IX – 2-5-5- Conclusion

As we have seen, by combining these various possibilities, any shape can be obtained as long as it is accessible to the machine.
For our impression this is possible including a digging a post.

Precision is a function of the instrument and the desired speed. A good fairly fast method lasting one or two hours allows a sculpting precision of a few microns on soft or very hard metals.

We do not loose the 5 μ precision in reading by our analyzer tube.

B- Special problems of the crown in fixed prosthesis and all other types of metal

IX – 2-5-6- Classic cast of the crown

The classic cast crown can be sculpted on some kind of pre-formed crowns as the "ions" would but in gold. This avoids loss (certainly recoverable since not melted) of gold or other materials.
It seems to me that electroform i.e. the electrolytic deposit of metal has a definite advantage.

IX – 5-6-1- Electroform

This technique lets us avoid the use of pre-formed crowns. If we consider the sculpted impression (plus the percentage dedicated to the cement) as a punch, the deposit will be done in a constant thickness starting from the base.
If we recall that the faster the electroform, the greater the risk of parasites, and considering the factors seen in [83], we can deposit 0.5 m/m of gold in one hour which is a sufficient time value for a crown.

The punch is the impression. Then the ideal information of the crown is sculpted with the least loss while avoiding internal sculpting of our crown. The destructive punch is preferable because removal from the mould would be obvious. This procedure also allows us to conceive a succession of materials as if in a sandwich, thus achieving ideal cooperation and perhaps allowing to avoid gold on the surface (interaction of mercury filling and gold cancelled) – see drawing 75 c).

This way, we could do deposits of materials that come close to the color and shine of teeth, avoiding porcelain on all teeth.
The interest would be in avoiding porcelain fractures and in having the possibility of metallic deposit everywhere (the era of visible crowns would be over).

### IX – 2-5-6-2 – Bridge

This could be constructed in the same way. The exterior sculpting would be done progressively and a very fine and theorical contact point would be acceptable.

Welding with laser would be allowed if the crowns were separated at the end (very fine contact points) – see drawing 75 d).

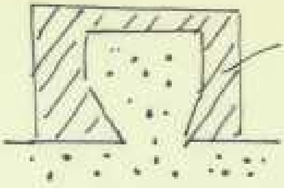
The advantage of sculpting one piece is obvious (time, the metal's properties).
The advantage of laser, as we saw above, is that it can be done against a ceramic without altering it. The metal grains do not grow bigger. Punctiformal weld of 25 μ is unusually solid.

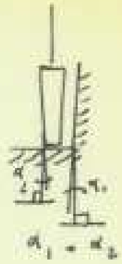
### IX – 2-5-6-3- Ceramic crown, crown with a screw

All it takes is to sculpt the electroform deposit with the program. A judicious system of coupling using laser cutting [87] or any other electronic bombardment [86] would allow this high energy to pierce the crown, the inlay body (subcrown) in several spots thus afterwards obtaining the carving in the mass on milling sculpture holes (see drawing 75 c).

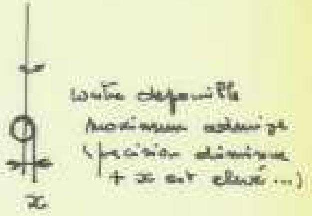
### IX – 2-5-6-4- Satellite

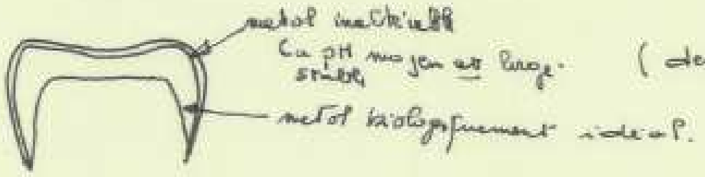
The stellite problem is facilitated (theorically speaking) by the chemical milling system by installing a flexible mask according to the cutting drawn by the computer, then putting a conduction deposit for instance or a chrome cobalt alloy deposit on a resinous material.
The stellite is deposited directly (see drawing 76 a). This would allow to obtain the sandwich or zones of choice of metal while changing the masks in the course of operation (greater elasticity, etc..) – see drawing 76 b).
We can also accept cutting the stellite by a line traced by the laser [77].
Here again we avoid casting and can add attachment freely by welding with laser.




(dessin 75a)

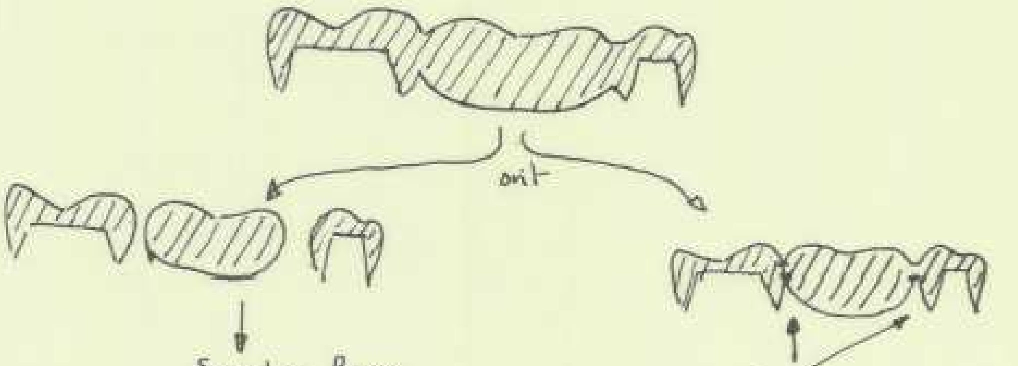


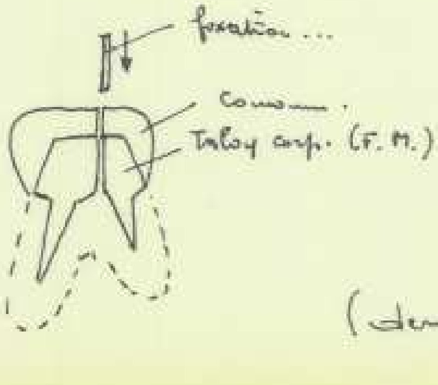

(dessin 75b.)

couronne sandwich

(dessin 75c)




(dessin 75d)




(dessin 75e)

IX – 2-5-6-5- Root abutment

By putting the post in place, the deposit can be done on this post (see drawing 76 c) or in its place.

IX– 2-5-6-6- Adjusted crown

We only need to carve the crown's interior doing away with excess metal but retaining the advantage of cohesion at the collar (see drawing 76 d).

IX – 2-5-6-7- Conclusion

Thus we see that using the electroform process with or without a mask, we can obtain crowns with little loss after sculpting.
These can be any kind of crowns and the laser can work on them or weld them. Metallic combinations allow us to join metals in selected topographic zones and in successive chosen layers. The ideal drawing of a prosthesis and the ideal sculpting of a crown are guaranteed to be close by 5 to 10 μ.

Welding can be avoided but can also be used. Only one is currently accepted for this : high energy bombardment [laser or electronic bombardment or the wonder ultrasound welding 854]. Any kind of shape can be obtained. The field of study would be positive considering the arrangements possibilities and precision available. Thus we can say that milling follows precision analysis. It is the only long part of the operation.

- milling 1 hour maximum (impression)
- deposit 2 hours maximum (crown)
- finishing milling 2 hours

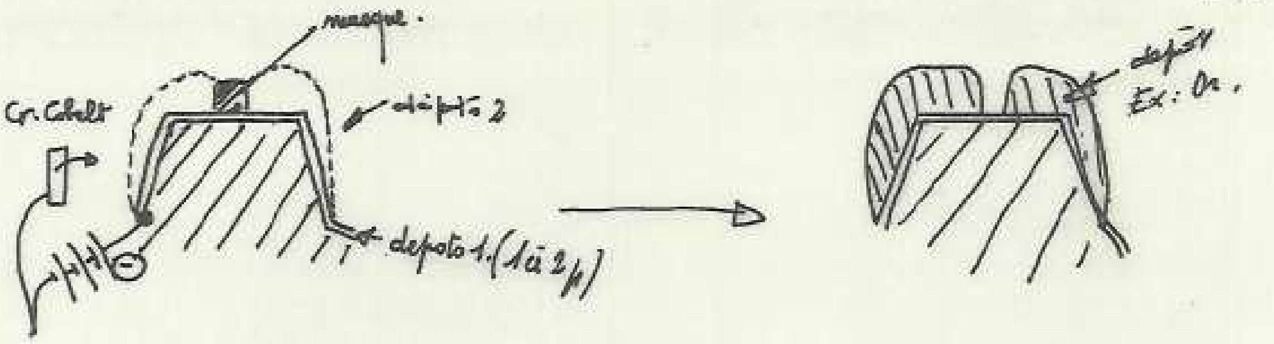
In five hours one complete bridge or one crown can be sealed after carving. The time saved is several weeks. The price remains to be studied but seems to be very favorable even in current theoretical conditions.

We can be reproached for making a catalog of possibilities. To understand why, we must see why this choice is necessary and a selection is made : milling and electrochemistry can be fixed at the same approach head. The electroform bath can be coupled to a sculpting machine setting the deposit time according to the program.
Finally the laser could be amplified by a gas laser, for example to allow welding or two lasers can be combined, one helium-neon and one ruby.

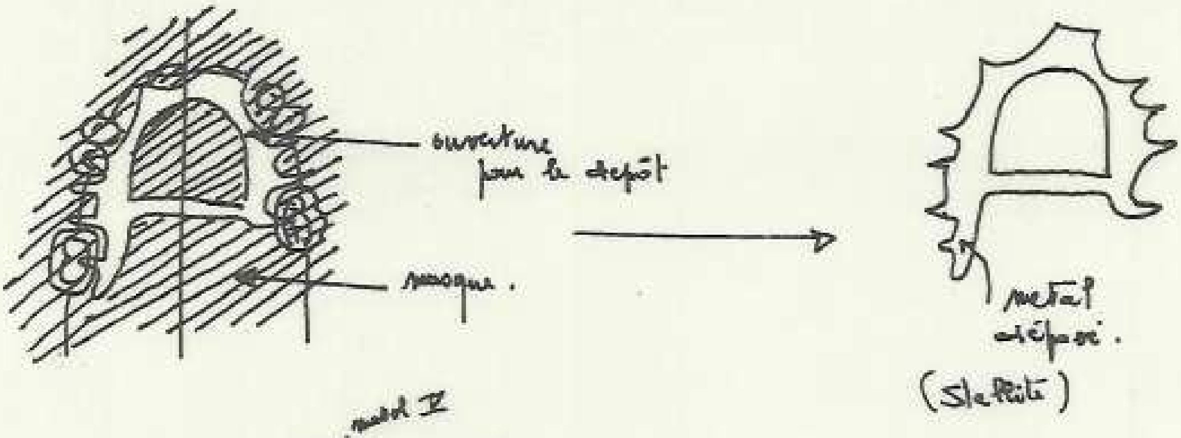
1°/- Thus any form, any metal, any combination of metals, any weld (welding plastic by ultrasound replacing auto-polymerizable resins) are obtained by this system with a precision of 5 to 10 μ (according to current technical possibilities). With our classic methods we work with a precision of 100 to 500 μ.

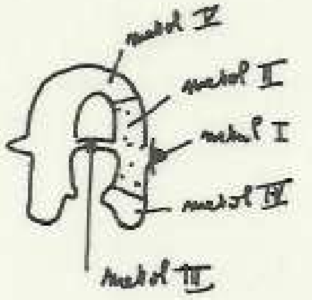
2°/- We do away with any changes in condition even in welding. We therefore do not intervene in the primary variations (Chapter 1) because we carve an established piece and balance it with surrounding systems.

3°/ - We almost entirely cancel secondary and tertiary variations by cancelling manipulation and risk of partial or total destruction of the impression.
What must be understood is that the piece is not accessible to the human hand until it is made into a crown. In other words, we cannot modify the sculpting by our manipulation.



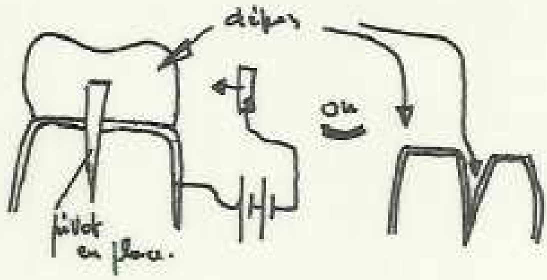

(dessin 76 a)



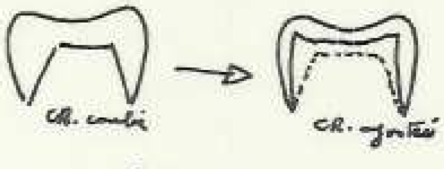




(dessin 76 b)

Stellite Sandwich




(dessin 76 c)



(dessin 76 d)

## General conclusion

We have described the great principles which link the object and its hologram. In the addition as well as the laser and hologram chapters, we have insisted on its advantages and disadvantages.
The simple reproduction of a print doesn't justify this method, even it is more precise; the starting cost price being relatively high, we propose, more than the simple print taking, the realisation of all conjoined prostheses pieces (crown, bridges, capping…) and adjoined (complete skeletal …), the setting up of posts and contention splints, we try to justify the inlay with relations to the silver amalgam which, in our view, would no longer have reasons to exists if only for economical reasons.
Finally, a few original applications are proposed.
The device will be made of several parts:

- inside the dental practice, a helium-neon laser with an optical fibre and a fixed plate for the mouth (see drawing 69a)
- there will be a restitution and analysis with a T.V. analysing tube
- the gathered information will be transmitted to a computer via a terminal to a research centre where the programmes will be established (see drawing 69b)
- from this centre, via the same terminal, the digital command information is sent to the high precision milling machine (see drawing 69b)

The crown or the skeletal device will thus be totally realized in one or two hours after the cut.

In this paper, we describe the classical print and why it is inexact (chapter I), we define the laser and its advantage (chapter II) then its action on the organism (chapter III).

Then, in chapter IV, we realise and define the hologram. In chapter V, we analyse with an analysing tube then create a program for each case, (chapter VI), all of this (chapter VII) meaning a digital command for the milling machine. These milling machines (chapter VIII) are used depending on the cases (chapter IX).

To short-circuit eventually the total reading, we recommend to report to chapter IX and eventually if an interest is struck, get back to previous chapters.

The reading is done in nano-seconds, the analysis in a couple of 1/10° of a second, the programming a few minutes and the sculpture in one or two hours….

The precision is 5 to 50µ depending on the chosen technique.
The possibilities of the optical print are essentially linked to the fact that we use the data that the coherent optical offers us (chapter II) about the biological field largely studied (chapter III) and the electronic data (chapter IV and V) applied to a computer (chapter VI), all of this realized using a digital command milling machine (chapter VII and VIII).

The rejection of the classical print comes from this absolute character of imprecision, conservation and reproduction all too often problematic, from the fragility of the laboratory time, too long and too linked to the experience of the prosthodontist. It also comes from the aggressive psychological character which the classical print represents inside the mouth.

The secondary print, linked to the fact that the parameters are modified, enables the realisation of a splint or a interesting visualizations without a bloody method.

This work represents a preliminary ensemble to a vaster program.

Reconstitution of fictitious objects (from the hologram specialists)
"The photographic plate constituting a hologram only has variations of blackening and there is no reason we can't reproduce them artificially. Thanks to the computer, we calculate the amplitude emitted by a fictitious object in any plan. We add auxiliary amplitude which plays the role of the amplitude produced by the coherent wavelength. The computer calculates the resulting intensity: a printer linked to the computer produces on a page these intensity variations. All that's left to do is a photo properly reduced to get a real hologram. We can thus recreate, in 3D, objects, which don't really exist" [297].

We hope that this modest thesis and bibliography have opens our profession to other researches.

N

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