

Transactional Quantic Microphysics, Principles and Applications



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Jacques Lavau editor
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3 The atomic limit, its fundamental quantities.

Professor Castle-Holder:

- First matter: the atomic limit, of which I will recall some fundamental quantities.

The **Avogadro-Ampère constant**: six hundred and two thousands two hundreds and fourteen of milliards of milliards of molecular units in a mole (we had called it molecule-gram, in the past). For instance six hundred and two thousands two hundreds and fourteen of milliards of milliards of water molecules in 18.0153 g water. I have dropped some decimals.

The quantum of action per cycle, discovered by Max Planck (1858 – 1947) in December 1900:

$$h = 6,6260755 \cdot 10^{-34} \text{ joule.second/cycle} = \hbar = 1,05457266 \cdot 10^{-34} \text{ joule.second/radian.}$$

10^{-34} , it is a hundred of milliardth of milliardth of milliardth of milliardth (here, of joule.second/radian).

Professor Marmot:

- Either you are a traitor, either a donkey, estimated colleague! You have just written that $h = \hbar$, when we all teach our students that they are very different!

Professor Castle-Holder:

- It seems that you did not notice that the difference is the unit of phase or cycle. The Dirac's form uses the radian, though the Planck's form uses the whole cycle, but h or \hbar remains the same physical constant. The physicist pays attention to the physical units, when the mathematician does not even know they exist.

Open-Eyes:

- For the sake of clarity, you may replace the last unit **J.s/rad** by the unit of angular momentum: $\mathbf{m} \wedge \mathbf{kg} \cdot \mathbf{m} / \mathbf{s}$, where the caret \wedge denotes the multiplication of two perpendicular lengths; the first length is the lever arm of the linear momentum, otherwise said, what matters is the outer projection of the lever arm on the linear momentum. It is an outer product, maximized when the two factors are

perpendicular vectors. So \mathbf{h} is a quantum of looping, though the Maupertuisian action (Pierre Moreau de Maupertuis 1698-1759) is a circulation of a momentum, or sum along the path, of the inner product of two vectors (maximum when they are colinear, when one is exactly its inner projection on the other). An irreducible difference of nature.

The symbol caret \wedge denotes an outer product. Alas the french readers of french books are misled by the french tradition: to improperly use the caret to mean a *cross product*. Alas, this traditional *cross product* violates both the mathematical coherence and the physics. The outer product of two vectorial quantities is an antisymmetric tensor, of rank 2. For pedagogical needs for the workshops, I have translated “*antisymmetric tensor of rank 2*” into “**gyror**”.

Harasser marmot:

- Ignorant! Heretic! This *krank* deludes himself that two quarters of a whole turn make a half turn! Let's all league to ban him from all Usenet!

Open-Eyes:

- I recall that this harassing marmot, frenzied invader, is not a physicist, and ignores all about the use of dimensional analysis in physics. Despotic, ignorant and presumptuous, he deludes himself in believing that physics is just a lean-to, annex of the maths he learned years ago.

We do not adhere to these erring, alas traditional. Here are some physical quantities which are not vectorial by gyrotorial: an (angular) moment of force, an angular moment, a spin³⁴, an angular speed, a magnetic field \vec{B} , a magnetic moment...

The bulk of the course for the geometric syntax of the physics is on the wiki:

http://deontologic.org/geom_syntax_gyr

The quantities about the atomic limit, continuation.

Professor Castle-Holder:

- Light celerity: $c = 299\,792\,580$ m/s.

Orders of magnitude: The Moon is at 1.28 light-second from the Earth, the Sun is at most at 499 light-second from us, that is between eight minutes and eight minutes and twenty seconds. Jupiter is at an average distance of 2595 light-seconds, or 43 light-minutes.

Charge of the proton: $1,60219 \cdot 10^{-19}$ C.

« C » denotes the coulomb, unit of electric charge.

³⁴ **Spin**: elementary angular moment, without equivalent in macrophysics.

When I was a kid, the definitions of the ampere and the coulomb were electrochemical, based on the weight of silver electro-plated on the cathode: one coulomb plates 1.118 mg of silver. So it needs six hundred and two thousands two hundreds and fourteen of milliards of milliards of silver cations, or any other monovalent ion, to carry one coulomb.

Mass of the proton: $1.67265 \cdot 10^{-27}$ kg.

Mass of the electron: $9.1093897 \cdot 10^{-31}$ kg

Atomic nucleus: Composed of Z protons and Y neutrons, it holds Z electrons to form an atom.

Atom: Only one nucleus, escorted with the right number of electrons to balance the electric charge of the nucleus.

The **atomics** deals with the electronic cloud around the nucleus.

The nuclear physics deals with the nuclei of the atoms.

Molecule: several nuclei, bound by electrons engaged in covalent bonds, that is sharing of pairs of electrons of opposite spin, in the most far orbitals of the atoms, plus eventually some mixed bonds or hydrogen bonds.

Ion: atom or molecule where the number of electrons does not balance the number of protons.

Anion: negative ion, more electrons than protons. Examples: OH^- , SO_4^{--} , HCO_3^- , Cl^- ...

Cation: positive ion, fewer electrons than protons. Examples: Na^+ , Ca^{++} , H_3O^+ .

Electrolyte: a solution containing anions and cations, so able to conduct electric current. The most common electrolytes are aqueous solutions but other solvents exist, and molten salts are electrolytes too.

Open-Eyes:

- De Broglie Wavelength corresponding to the mass of the electron (said *Compton length* by the American):

$$\lambda = \frac{h}{mc} = 2.42631058 \cdot 10^{-12} \text{ m}$$

Its inverse the electronic wave number, that is $4,121,483,900 \text{ cm}^{-1}$, or more elaborated, the electronic **wave vector** intervene in the reactions between electrons and gamma photons.

Professor Castle-Holder:

- When we only say wavelength, we discard the direction of propagation. Implicitly, the implied unit of phase is the cycle or 2π radians. The wavenumber is used by the spectroscopists.

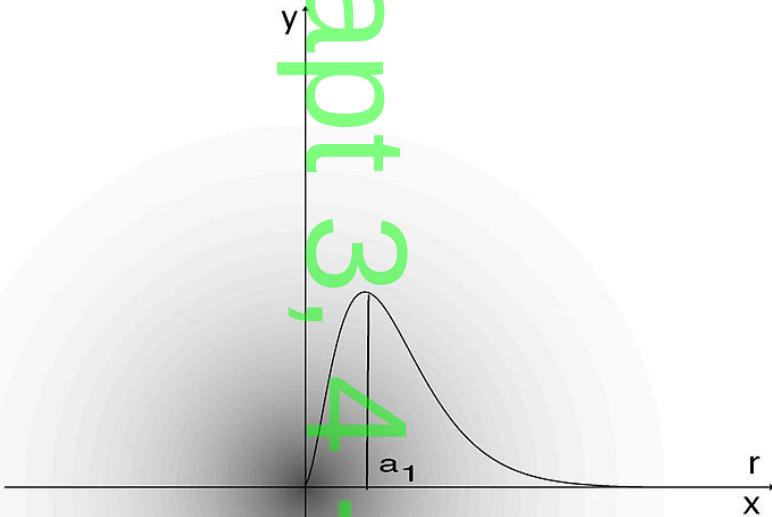
Another craft prefers the wave vectors, but change the unit of phase, preferring the radian. It is not a matter of principle, but of local habits.

The diameter of a hydrogen atom: about 0.11 nm (a hundred and ten picometers, or 1.1 ångström³⁵). It is intrinsically fuzzy.

Open-Eyes:

- Here is an image of the density of the electron in its fundamental state around a nucleus of hydrogen:  Fig. 3.1. (image from the public domain).

35 Ångström, ([ɔŋ.'strøm/](#)), is 100 picometers, 10^{-10} m.



This electronic density is the square of the amplitude of the stationary wave of the Schrödinger equation. Squared or not, it remains an exponential function of the radial position: $\exp(-r/r_0)$, or $\exp(-2r/r_0)$ for the square, with its maximum at the null distance, that is just on the nucleus.

The reader has noticed the spherical symmetry, the fuzziness and the large size of this electron. This contrasts with familiar popularization by images or videos, which presents you a small planet orbiting around a central star. However, the trajectory of a planet is a spire, which has none of the symmetries of a sphere, nor

worse, of a fuzzy sphere. This is a major contradiction in the corpuscularist idea. Seen from the outside, the chemical properties of a hydrogen atom are those of its electron, captive of a central H^+ ion. Notice that you can find atomic hydrogen only in intersideral space. In the pressure bottles, or in the laboratory you only find the dihydrogen molecule H_2 in the gaseous state, and it is much more difficult to describe and draw. We will see later the electronic map of a dinitrogen molecule N_2 .

Professor Marmot:

- Shame on the perfidiousness of this weird science-venturer! Instead of telling as he was taught to “*Probability of finding the electron*”, he says “*density of the electron*”! Instead of denying the wave, as he was taught to, he reinforces it, and he disavows the corpuscular aspects! What a scandal, as we had physically defeated Erwin Schrödinger and his wave in December 1926³⁶ and October 1927! What a shame, and what a weird mind!

36 <http://citoyens.deontolog.org/index.php/topic,1141.0.html> : **Les procédés employés par Niels Bohr pour vaincre Schrödinger**: The telling is by Werner Heisenberg himself, though he had much to earn in defeating Erwin Schrödinger, either by a loyal or by a disloyal fight.

Source : Franco Selleri. *Le grand débat de la physique quantique*. Champs Flammarion, Paris 1986. Page 96.

This telling is confirmed from second hand by Emilio Segrè, in *Les physiciens modernes et leurs découvertes*. Fayard, Paris 1984 for the french translation.

Selleri quotes the original source with the letter from Heisenberg:

S. Rozenthal, ed. *Niels Bohr*. North-Holland, Amsterdam, 1968.

Quotation: Schrödinger had to face a difficult fight in Copenhagen. Bohr invited him to give a lecture at the end of 1926 “*and asked him to, not only give a lecture on his undulatory mechanics, but also to stay in Copenhagen enough time for discussing of interpretation of Quantum Mechanics*”.

Heisenberg describes so the intensity of the fight:

“*Though Bohr was really an obliging and attentive person, he was able in such discussions about the epistemological questions he considered as absolutely vital, to insist in a fanatic manner, and with a terrifying inflexibility on the complete clarity of all the arguments. After hours of wrestling, he still could not resign himself in front of Schrödinger, to admit that his interpretation was insufficient, and even unable to explain the law of Planck. Each attempt from Schrödinger to evoke this embarrassing point was refuted, slowly, point by point, in painstaking and endless discussions. Probably because of this overworking, after some days Schrödinger fell ill and had to stay in bed in Bohr house. But even then it was difficult to keep Bohr far from the bed of Schrödinger...*”

And Heisenberg concludes: “*Finally, Schrödinger went out of Copenhagen rather demoralized, when at the Bohr institute we felt we got rid of the interpretation given by Schrödinger to the quantic theory, which hastily used classical undulatory theories as models.*”

So were treated the fundamental questions, and so a small-group became hegemonic: by sheer violence.

Curious:

- Let's apply your scientific discipline: from what experimental protocol does this image result? How did you measure that?

Professor Castle-Holder:

- Not any direct experiment is possible. In macroscopic electrostatics, it would be possible to place a small trial-charge at a varied distance from the central charge, and to measure the local potential, and even the field. At the Palais de la Découverte, they can demonstrate it to the public. But it is impossible to set a *small test-body* around the proton as we could in macroscopic electrostatics, neither for measuring the potential, neither for measuring the local electronic density. Much worse than a practical impossibility, it is in principle impossible: no *small test-body* smaller than a whole atom may exist. Nor we ever will have a micro-mover, able to set around this mythical *test-body*. We only can give the computed model of the bound electron, by resolving the Schrödinger equation. In this simplest case, we can carry the computing up to the end. Here is the solution for the lower and stable state, where the distance from the nucleus is noted ρ :

$$R_{10} = \left(\frac{Z}{a_0} \right)^{\frac{3}{2}} .2 e^{-\frac{\rho}{2}}$$

But we have many indirect proofs of the validity of this kind of electronic density images in the atoms or molecules or crystals: the compressibility of crystals, the thermal dilation, the frequencies of the vibrating gaseous molecules able to couple with an infrared photon, to absorb it or to emit it, predicting the optical properties of the dye molecules, etc. So concerning the principle, we have not more any chance to be wrong.

Curious:

- So? You only have indirect proofs?

Professor Castle-Holder:

- Indirect indeed. We do not have any other way.

Curious:

- How annoying! In microphysics, I can no more use my senses nor my muscular proprioception, when they are still usable in macroscopic mechanics.

Open-Eyes:

- And even provided that the mathematization would be not deceptive nor stupid! Which alas is not always guaranteed. Your proprioception is flouted when a teaching pretends: “**Then one has an angular speed vector that climbs along the axis**”. They do not help, these inexcusable traditions, that are repeated from generation to generation... It is one of the more violent abuses, where the rules of the honest and scientifically validated unsensorialization are openly breached, precisely where nothing justifies any unsensorialization of the tools for electromagnetism and mechanics, in denial of reality.

Curious:

- So? How to verify you are not telling “*just so stories*”, in the fashion of the frauds from Sigmund Freud and his church? The records do not encourage a blind trust.

Open-Eyes:**- Demand lots of experimental reality-testings.**

Even the rationale Mechanics is denied by the bulk of people, included the students, without hesitation nor reflection, as soon as they do not recognize a scholar case; it is a part of the civil war against the learned ones. In Annex G, we give you many experimental situations you can verify in a common life frame. But in microphysics, no pity: we are not more in our familiar sensorial world, and we had to build largely unsensorialized tools. Here are some physical quantities used in microphysics, which have a correspondent in our familiar macroscopic world: the masses, the linear momenta, the energies, the angular moments, the potentials, the fields, the electric charges and the magnetic moments are of the same nature as they are in our familiar macroscopic world.

The only one solution for you laymen, is to demand experimental reality-testings. Alas, the custom of the popularization magazines is not up to their duties: like African griots³⁷, they emphasize the dramatization: “*This one wins on the other! Let’s swear fidelity to the brave general Tapioca*”³⁸, as he is the master of the situation!” then they multiply the fantastical interpretations, so toady to the suckers. Example: they cheekily repeat that the famous Schrödinger cat “*is in a superposed state, neither dead, neither alive*”, when of course, they remain unable to exhibit any experimental proof. They remain intoxicated by the hegemonic fairy tales.

37 Griot: african singer or narrator, paid to praise the prestigious genealogy of the powerful chief of the day.

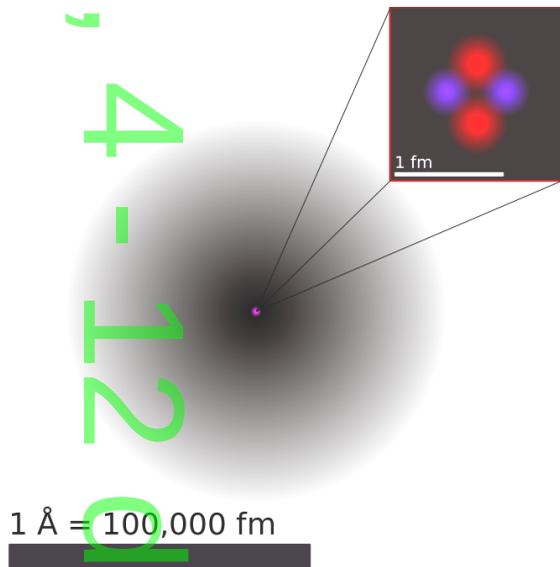
38 **General Tapioca, general Alcazar.** Cf. *L’oreille cassée*. By Hergé.

A problem more: nobody knows how to put you in front of an experiment which demonstrates clearly “*The Maupertuisian action, or the Hamiltonian action, it is that*”. Though we can achieve this result for the angular moment, but linking the two is more awkward that they make you believe.

Professor Castle-Holder:

- The atom next in complexity is the helium atom: two electrons, and in the nucleus two protons and two neutrons.

Fig 3.2. (public domain):



This atom is represented in its standard and stable state, which is again of spherical symmetry.

Read the prefix: femto_, from the Swedish *femton* = fifteen, denotes the power -15 of 10, that is the millionth of the milliardth.

The pico_ is the power -12 of 10, that is the

The Å or ångström (ɔŋ.'strøm), is 100 picometers, 10^{-10}m .

The helium does not chemically bonds in any molecule but can slip as interstitial in many metals and rocks. Its two electrons are in the same lower state, of

spherical symmetry, they only differ by the spins, which are anti-parallel, the two opposite spins make a pair, of null total angular moment.

Again an artifact induced by the constraints on the drawing: the helium nucleus is drawn flat, with colors. Nothing such exists, nothing that is flat, with colors. The reality of a α nucleus is beyond the means of a draughtsman. So are the objects the Quantum Mechanics handles.

Open-Eyes:

- QM, otherwise said Microphysics.

Professor Castle-Holder:

- There is hardly one kind of exceptions where the QM overflows in the macrophysical domain: when herds of bosons intervene (particles with an integer spin = 0 or 1, apt to pack together, ruled by the Bose-Einstein statistics). Bosons are apt to pack together in the same quantic state. Applications: the lasers, the masers, the superconductivity³⁹, the super-fluidity of helium 4, the interferential astronomy, even with a large base.

Open-Eyes:

- Another half-exception: all the electric contacts, as you have so many around you, in your car, in your house, can only work by “*tunnel effect*”, that is that the wavelength of each conduction electrons⁴⁰ as it is at the Fermi energy⁴¹, is larger than the gap between the to nearing conductors, approximately in quasi-contact, and larger than the thin oxide layer (not seeable at naked eyes) that covers each. Ah yes, each conduction electron is much larger than the interatomic distance of

39 In a **superconductor**, below a critical temperature, the electric resistivity falls to null. Alas, provided that the magnetic field is not too strong... Mechanism: the electrons associate by pairs – said Cooper’s pairs – with one or two phonons, and their wave travels through the entire crystal in the way of a boson, of integer spin.

A **phonon** is a unit of vibration in a crystal. Further explanation at § 4.2.

40 **Conduction electron**: at the top of the energies occupied by the electrons of the metal. Only a small minority of metals have the conduction band half-filled, with only one conduction electron by atom: copper, silver, gold, aluminum, gallium, indium, plus the alcalines. These ones are the only good conductors of electricity. Most metals have the conduction already fulfilled, with two electrons per atom. Their electrical conduction, and consequently their thermal conduction is less good, and much more difficult to explain: by recoverings of the Brillouin zones according to crystallographic directions. It is an anisotropic conduction in these metals.

An **anisotropic** property differs according to the direction.

41 **Fermi energy** in a metal: the highest level of electron energy occupied by an electron, at the temperature of the absolute zero. The zero is taken at the level of the most bond electrons.

copper or gold or aluminum of the conducting contact. No one popularizer at the TeeVee never told you that. But how a mediatic sorcerer could dazzle you by their *kakarakamouchems*⁴² with a so common phenomenon as an electric contact? So the mediatic sorcerers keep mute on that.

Professor Castle-Holder:

- You have said too much, or too little! The tunnel effect gives a probabilistic result: some particles ought to never pass, but sometimes pass.

Open-Eyes:

- Developing: the interposed non-conductive layer – combined oxygen, adsorbed⁴³ dinitrogen, adsorbed water – may shoot back electrons, as also do phonons, impurities and dislocations. If no generator would be behind to impose its rule, the accumulation of electrons on the negative side of the junction should slow the other electrons coming from the upstream. So the resistance⁴⁴ of the circuit increases; in electrocinetics⁴⁵, the contact-junction produces a supplementary drop of potential⁴⁶. What you wanted to translate into probabilities remains a mere increase of the global resistance of the circuit: the contact resistance is noticeable. The electricians easily live without knowing that they handle quantic phenomena each time they switch a circuit on.

Another exception, which permits all the electrotechnics, the electric motors, the alternators, the transformers, and the Earth magnetism too: the **ferromagnetism**⁴⁷. A similar phenomenon is the **ferrimagnetism** which permits the ferrite bars in your radio receptor, and the miniature transforms in the switch-mode power supplies which now are everywhere in your houses. In

42 Molière, *Le bourgeois gentilhomme*. « What ? *Kakarakamouchem* means my sweet darling? How it is admirable! What an admirable language is that Turkic! ».

43 **Adsorption**: weak bond of a molecule on the surface of a solid. If it retakes its liberty in gaseous form, it is said desorbed.

44 **Electrical resistance** of a circuit: the quotient of the difference of potential by the intensity of current. Unit: Ohm = volts/ampères.

Intensity of a current: how many electrons per second. The macrophysical unit is the ampere. One ampere = six milliards and two hundreds forty two millions of milliards electron per second (many decimals omitted).

45 **Electrocinetics** as opposed to electrostatics where no charge move: in electrocinetics the currents exist, the charges are moving.

46 **Electrical potential**: similar to the height of water in hydraulic. If you hoist a charge + to a higher potential, you increase its potential energy.

47 The **ferromagnetism** is known in macrophysics as the magnetism of the iron and some alloys. The **ferrimagnetism** is in some oxides. For instance the magnetite Fe_3O_4 .

ferromagnetism, all the spins that are unpaired in each atom, have the good will to organize in herds, all in the same equiplane ⁴⁸, and sign of rotation, in Weiss domains ⁴⁹ enlarged enough to have macrophysical effects.

Professor Castle-Holder:

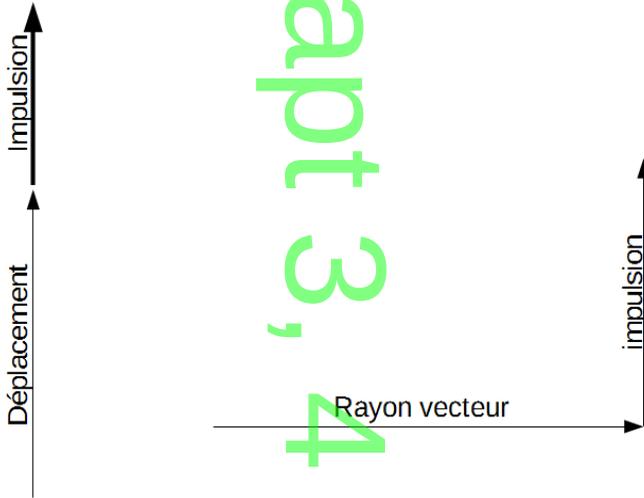
- Nobody knows why the constants mentioned above are such, and not something else. Nobody knows why the electrons have all the same charge, and why this one. Nobody knows why the Planck quantum of action is $6,6260755 \cdot 10^{-34}$ joule.second, but we have acquired the certitude that it is indeed a universal and fundamental constant.

Open-Eyes:

- Planck quantum of **looping**: $6,6260755 \cdot 10^{-34}$ joule.second/**cycle**. The initial definition of action by Pierre Moreau de Maupertuis was an inner product of two vectorial quantities: the product of the linear momentum by the way made, or circulation of the linear momentum. Whereas the angular moment is an outer product of a lever arm by the linear momentum, that is why a unit of angle, or of cycle, or of phase intervenes in it. So is not the action of Maupertuis, neither of Hamilton and Jacobi.

48 **Equiplane**: the equivalence class of all the planes having the same orientation of plane.

49 **Weiss domain**: in a crystal, a domain where the magnetization has the same direction of plane, and the same sign of rotation.



L'action est un produit intérieur de vecteurs.

Le moment angulaire est un produit extérieur de vecteurs

To do an **inner product** of two vectors, one begins by an inner projection of one vector on the other. And the cosine is an even function. The result has no orientation in the space.

To do an **outer product** of two vectors, one begins by an outer projection. And the sine is an uneven function. The order of the operation matters, it always gives a **direction of rotation** in the plane direction of the equiplane given by the two vectors.

So this is a fundamental problem, on which only a few paid attention. The twist of this story is that in 1924, Louis de Broglie had applied the first definition to the wave, along with the Bohr orbit, and two years later it allowed Erwin Schrödinger to prove that this Bohr orbit does not exist. We still have some work before us, to put all that upright.

Professor Marmot:

- What a scandal! This science-venturer from the gutter never stops to say the contrary of what we all teach! Let's slaughter him with a grenade!

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Curious:

- Objection! Again here you have written lots of new words: “**spin, ferrite, ferri-magnetism, ferromagnetism, photon, tunnel effect, Fermi energy**”... You should explain all.

Open-Eyes:

- Acceptable objections. Do not forget to look at the footnotes, even when they are short. You will find a chronological glossary in Annex F. I invite you to have more patience, as I see we have to spend some more time on atomics⁵⁰. There it is manifest that we do not more do the same physics that the anti-transactionist copenhagenists do, and that with the same laws of stationarity of the stationary electronic wave around the nucleus, we do not present the same diagrams.

Professor Marmot:

- All that fuss is just futile and unimportant philosophical preferences! What matters is that you lower the head and calculate!

Open-Eyes:

- I intervene before the calculations; I intervene on the semantic axioms and the physical axioms, with the criterion they must be economical - and those of yours are not economical at all – but also that they adhere closely to the reality; where you are terribly failing.

Professor Castle-Holder:

- Nevertheless, it is time to shove the natural laziness of the readers, by giving them exercises, like in all serious handbooks.

Knowing that the mass of the proton is $1.67265 \cdot 10^{-27}$ kg, deduct its intrinsic de Broglie frequency.

We accelerate it under a potential difference of 500 V. Calculate its wavelength in the frame of the laboratory.

Compare this wavelength to some known inter-atomic distances, for instance in aluminum, 286 pm.

50 **Atomics:** a branch of physical chemistry, studying and predicting the chemical properties of the atoms according to their place in the Mendeleev periodic table, i.e. according to the structure of their electronic beviess.

Same questions with a bullet for an assault rifle, weighing 5 g: its broglia frequency as a bulk, then its wavelength in the frame of the laboratory, when its speed is 800 m/s.

How will you mount the experiment to show up and measure this wavelength?

The key is in Annex H.

So it will be evident to you that the mechanics is undulatory in practice only for minimal masses: electrons, protons, neutrons, etc.

Chapter 3, 4 - 12 dec 2017

4 The energy levels in an atom, a molecule, a solid.

4.1 Why these definite *energy levels*?

What was made evident by the spectroscopists along the 19th century. And exploitation of it.

4.1.1 Energy levels in an atom.

Open-Eyes:

- Louis de Broglie was the first to give a physical explanation in 1924, alas incomplete: The wave of phase of the electron may loop around a nucleus as a stable and stationary wave only if it has a precisely defined frequency and a phase celerity.

It can loop a turn in one cycle: principal quantum number $n = 1$.

It can loop a turn in two cycles: $n = 2$.

Three cycles: $n = 3$, etc.

The complete explanation was given two years later by Erwin Schrödinger in 1926: the wave equation he wrote had constant solutions for an atom only for electrons having a lesser energy than the one of the free electron, and only a *discrete*⁵¹ suite of stable states exists. There occurs an auto-quantification, by the proper values of the equation, depending on the boundary conditions. The lower state of energy still has $n = 1$ as the principal quantum number.

But from de Broglie to Schrödinger a revolution was done: the fundamental state has no more the symmetries of a turn, but of a sphere; and in that state said **S**, the electron has no more orbital angular moment. No, the electron does not “*turn*”, it does not *orbit*, but plainly **it is**, and is continuously spread around the nucleus.

Curious:

51 Opposed to a continuous set or subset, a set or subset is said **discrete** if it has a finite or countable number of elements, and is not dense.

Example: the suite of the inverses of integers $1/2, 1/3, 1/4$ is a countable infinite set, but discrete.

Counter-example: The set of the rational numbers **Q** is not discrete, as dense everywhere in the set of the **real numbers**.

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- That's odd: what you say is the contrary of what I had been told by videos.

Open-Eyes:

- I recognize which ones of the *great ancestors* did correctly their work. I sort it out, and *throw in the garbage cans of the History* what is not worth a crap.

When you read the original papers from Schrödinger, you see that what he wrote is the contrary of what his enemies, the winners of 1927, pretend in his back to be his views: The Schrödinger wave describes the electron, the stationary wave around a nucleus, and not "*the probability to see the apparition of the corpuscle*". The fact that this wave is stationary is binding. What the spectroscopists, then next the astrophysicists discovered for the 19th century, is that these stationary states of the atoms and molecules are universal, are the same in the whole universe, with a fine definition. The Planck constant which binds the frequency to the mass is the same everywhere.

During an atomic transition, either emitting a photon or receiving it, the atom (or the molecule) oscillate between the initial and the final state, and this transition takes some time. The frequency of the emitted photon is the **beat** between the initial broglian frequency of the atom, and the new one. Sure this difference is extremely small in relative value, but it is what the spectroscopist accesses to. The same difference at the absorption, except that the most energetic and quick state is the final state.

Curious:

- Do the spectroscopy and these spectra of lines exhaust all that we have to know about emission and absorption of light?

Professor Castle-Holder:

- Surely not! On the one hand, the thermal agitation in a gas broaden all the spectra lines, up to rendering them indiscernible if the temperature at the surface of the star is high enough. The tungsten thread of our incandescent lamps does not emit a spectrum of lines, but a continuous spectrum depending on the temperature, according to the law of Planck.

On the other hand, many are the absorption mechanisms that are not especially spectral.

Surely two emissive mechanisms are not bound to any stationary state, so not so spectral: the braking radiation or *Bremsstrahlung* and the synchrotron radiation.

Open-Eyes:

- The braking radiation is observed around nuclear reactors when they are immersed at the bottom of a pool; it is a bluish light. It is produced when high energy particles coming from the reactor have a higher speed than the celerity of light in this material.

The braking radiation or *Bremsstrahlung* also occurs from the high energy electrons incurring on the anode of an X-ray tube. For a radiocrystallographist either this *Bremsstrahlung* is favorable if he intends to do a diffractogram of spots, according to the protocol from von Laue (1912), so he needs a polychromatic radiation; either it is an annoying parasite if he wants to do a diagram of powder, according to the protocol invented by Peter Debye and Paul Scherrer in 1916; then he must use filters to stop the *Bremsstrahlung*, and to let pass only the $K\alpha$ ray of the anticathode metal.

A gigantic facility for synchrotron radiation, where you must reserve your beam time a year before, with a detailed and precise file for your project of experiment, is the ESRF in Grenoble. At each bending imposed by the electromagnets to the beam of electrons at 6 GeV, a narrow beam of X-rays and gamma rays escapes tangentially. It is an extremely bright and narrow source, but widely polychromatic. It is up to the user to have mounted all the monochromators he eventually needs. Not any kind of stationary state of the emitting electrons nor before nor after the bending.

Professor Castle-Holder:

- Let us begin with a diagram and a table of functions about which we do not yet diverge, and that our curious reader does not yet know. Here are the energy levels of the unbound hydrogen atom (not bound in a molecule, not bound in dihydrogen).

On the left is the scale of the energies, in electron-volts from the fundamental level; on the right the scale is in wavenumber in cm^{-1} and the origin is inversed : from the free electron. Multiply by c , the celerity of the light, and you obtain a frequency. The oblique lines figure the spectral lines observed in the spectrum of the atomic hydrogen, that are *authorized* transitions (authorized by the transition rules) between stationary levels of the electronic wave. These stationary levels are figured by horizontal lines.

This diagram comes from Edouard Chpolski, *Physique atomique*, tome 2, Ed. Mir 1978.

Figure 4.1.

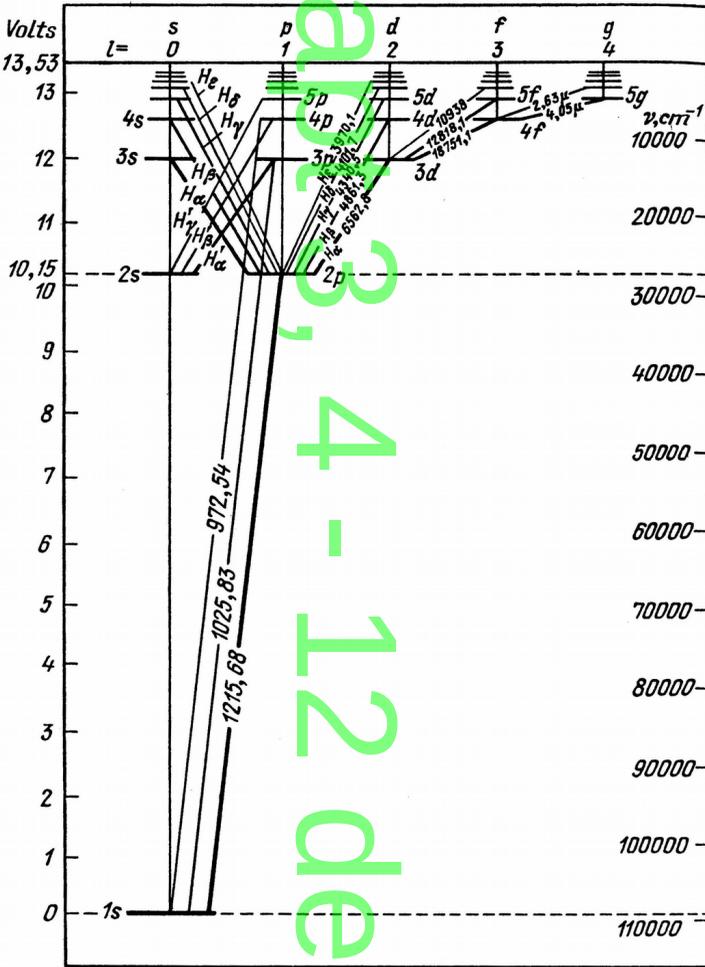


Fig. 26. Niveaux d'énergie de l'atome d'hydrogène (l'épaisseur des lignes correspond à la probabilité de transition)

The level 1s is the fundamental state, with spherical symmetry, already figured sooner. The levels 2s, 3s, 4s also have a spherical symmetry, but with respectively 2, 3, 4 disjoint zones, so 1, 2 or 3 spherical surfaces of transition of phase, with null intensity and null density. The level 2p has no more the spherical symmetry

but instead has a plane of frontier of phase. The level 3p has both a plane of frontier of phase and a spherical frontier. The level 3d has two planes as frontiers of phase. I let you complete for the levels 4p, 4d, 4f, 5p, etc. As the levels step up from the fundamental, their energetic differences decrease, and anyway, the levels have the ceiling of the free electron, 13.53 eV above the fundamental 1s, the most bound state.

Here you have the table of the exact mathematical functions for the stationary electronic waves of hydrogen, following the quantic numbers n , l , m . The spin variable is omitted here. Same source: E. Chpolski. The radius is represented by the greek letter σ . All along this presentation of the atomics, we keep the Schrödinger equation of 1926, not relativist, which is qualitatively enough for this task, and remains quantitatively very good.

States of a hydrogen atom

n	l	m	$\psi(\text{normed}) = R(r) \Theta_{l,m} e^{\pm im\phi}$	State
1	0	0	$\frac{1}{\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} e^{-\sigma}$	1s
2	0	0	$\frac{1}{4\sqrt{2\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} (2-\sigma) e^{-\sigma/2}$	2s
2	1	0	$\frac{1}{4\sqrt{2\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma e^{-\sigma/2} \cos(\theta)$	2p
2	1	+1	$\frac{1}{8\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma e^{-\sigma/2} \sin(\theta) e^{i\phi}$	2p
2	1	-1	$\frac{1}{8\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma e^{-\sigma/2} \sin(\theta) e^{-i\phi}$	2p
3	0	0	$\frac{1}{81\sqrt{3\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} (21-18\sigma+2\sigma^2)\sigma e^{-\sigma/3}$	3s

3	1	0	$\frac{1}{81\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} (6-\sigma)\sigma e^{-\sigma/3} \cos(\theta)$	3p
3	1	+1	$\frac{1}{81\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} (6-\sigma)\sigma e^{-\sigma/3} \sin(\theta) e^{i\phi}$	3p
3	1	-1	$\frac{1}{81\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} (6-\sigma)\sigma e^{-\sigma/3} \sin(\theta) e^{-i\phi}$	3p
3	2	0	$\frac{1}{81\sqrt{6\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma^2 e^{-\sigma/3} (3\cos^2(\theta)-1)$	3d
3	2	+1	$\frac{\sqrt{2}}{81\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma^2 e^{-\sigma/3} \sin(\theta) \cos(\theta) e^{i\phi}$	3d
3	2	-1	$\frac{\sqrt{2}}{81\sqrt{\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma^2 e^{-\sigma/3} \sin(\theta) \cos(\theta) e^{-i\phi}$	3d
3	2	+2	$\frac{1}{81\sqrt{2\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma^2 e^{-\sigma/3} \sin^2(\theta) e^{i2\phi}$	3d
3	2	-2	$\frac{1}{81\sqrt{2\pi}} \cdot \left(\frac{Z}{a_1}\right)^{3/2} \sigma^2 e^{-\sigma/3} \sin^2(\theta) e^{-i2\phi}$	3d

The binomial $2 - \sigma$ has one zero, the trinomial $21 - 18\sigma + 2\sigma^2$ has two zeros, etc.

Open-Eyes:

- But with the next diagram, the things get worse. The majority, not to say the hegemonic authors have coded the corpusculist theory of Born and Heisenberg with the soldering iron in the teaching handbooks. They graph the solutions functions only after elevating them to square. So we have to remake all the graphs.

Figure 4.3.

4.1 Why these definite energy levels?

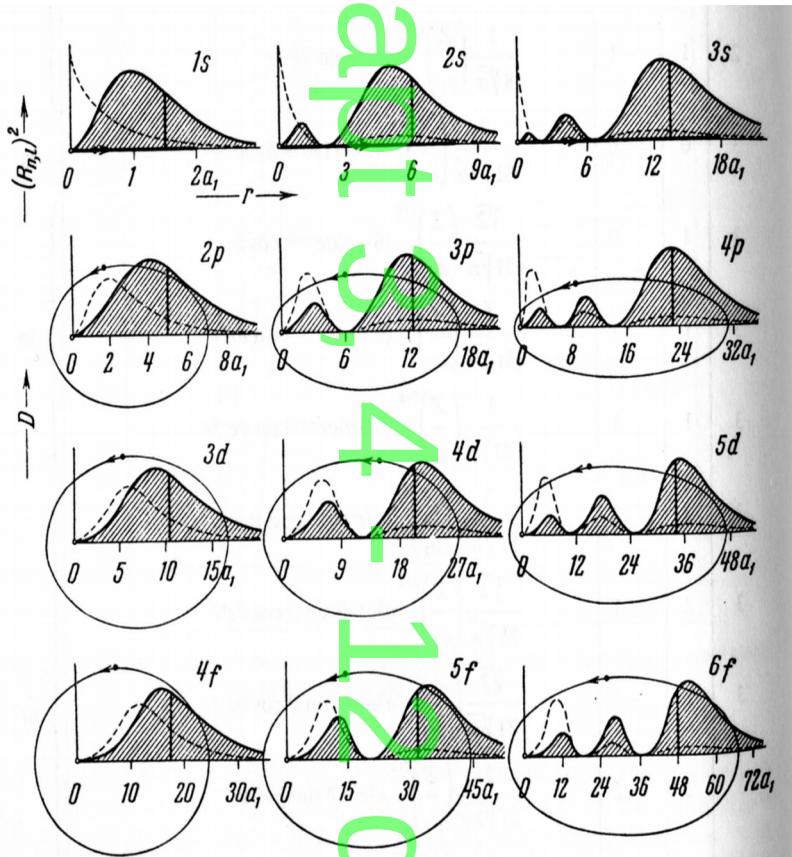


Fig. 27. Courbes de la composante radiale de la densité de probabilité $D = 4\pi r^2 (R_{n,l})^2$ pour différents états de l'atome hydrogénoïde. En pointillé est donnée la variation de la fonction $(R_{n,l})^2$. La position de la grandeur moyenne $\bar{R}_{n,l}^2$ est marquée par un gros trait vertical

OK, we will redo the necessary graphs, with the wave itself, and not its square, for the states 2s, 3s, 3p, (4p, 4d, 5d, 5f, 6f later). In blue at the screen, the punctual spatial density; in red it is multiplied by the square of the radius, giving the total presence of the electron at the distance represented by the absciss. You will notice how large are the higher states, compared to the fundamental.

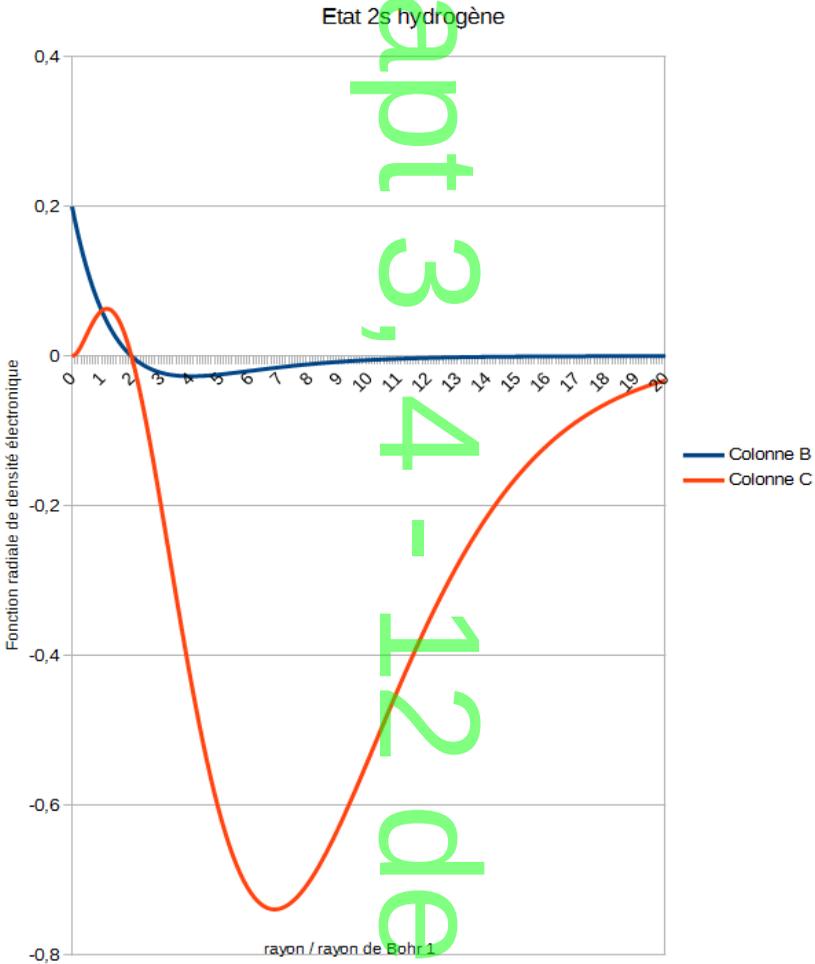
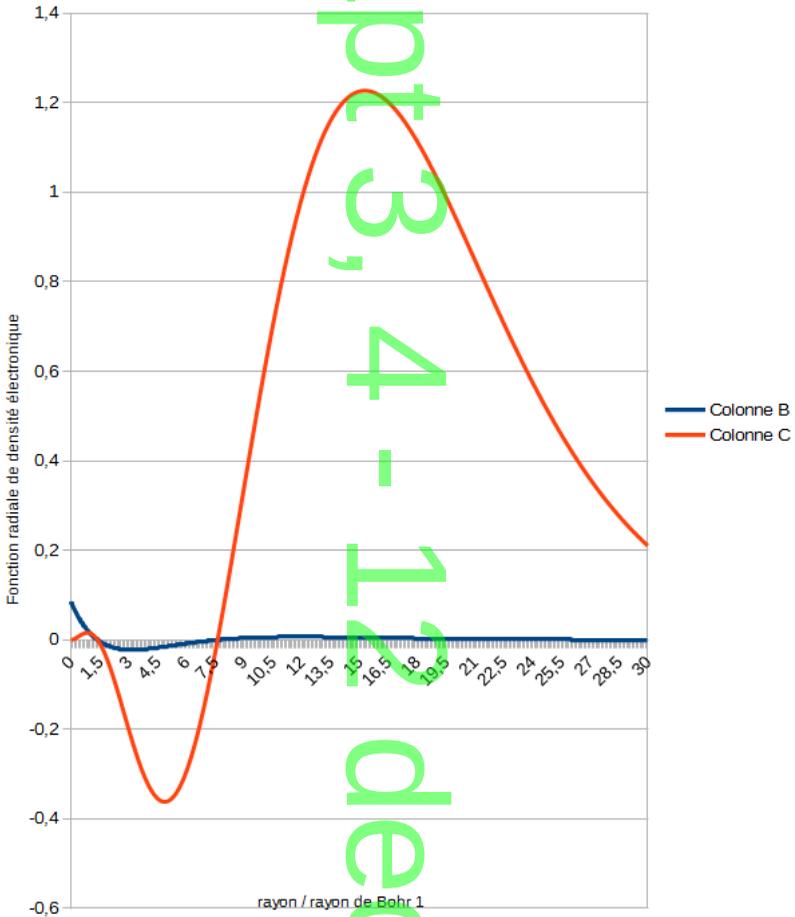


Figure 4.4.

See that for the 2s state, the density has a null at twice the Bohr radius. The phase changes of sign. 2s ==> two phase zones, one frontier of phase.

4.1 Why these definite energy levels?

Figure 4.5.
Etat 3s hydrogène



In the state 3s, the density has two zeros at 1.3775 and 7.6225 times the Bohr radius. 3S ==> three phase zones, and two frontiers of phase.

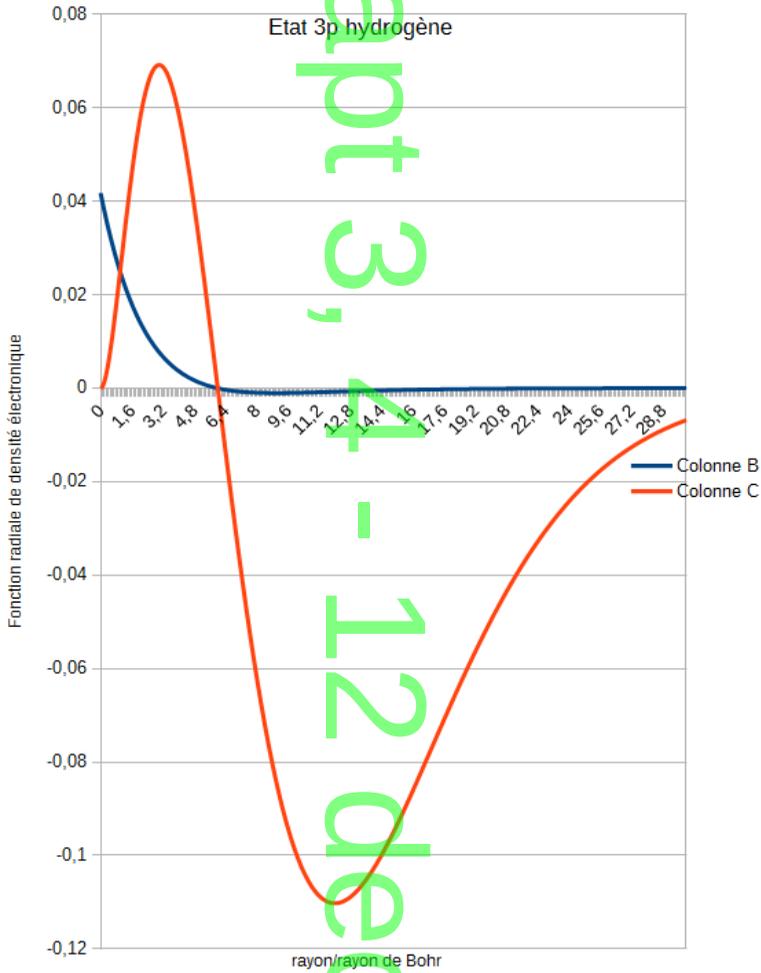


Figure 4.6.

In the state 3p, the zero is at six times the Bohr radius. Moreover, the density is divided in angle in two lobes, separated by a null density plane.

3p ==> four phase zones, separated by two perpendicular surfaces of phase frontier.

In University they carefully hid all that from you, as these stationary waves so precisely defined, it does not adjust to their “*probability of apparition of the gremlin and poltergeist corpuscle*”.

A warning is useful: Here we have solved the stationary and static Schrödinger equation, independent of time. So the flowing of time could be the one of the god of Isaac Newton. There is no propagation of the phase from one zone to the other in the electron; all is ideally synchronous. So is the simplified theory in 1926, before P.A.M. Dirac uses the relativistic frame.

Professor Castle-Holder:

- To complete this basis in atomics, you have to learn that the most the atoms are heavy, the most are electrically charged the nuclei, so the most the fundamental states dwell near the nucleus. So the remaining of the world does not notice them, and mainly discerns the most peripheral electrons. Very soon, the emission rays concerning the deep layers quit the visible domain, and belong to the UV and X domains. So is the Moseley⁵² law: $\sqrt{\nu} = k_1.(Z-k_2)$ published in 1913, linking the atomic number to the frequencies of the rays \mathbf{K}_α (and so the rays \mathbf{L}_α and \mathbf{K}_β too) for each element. k_1 and k_2 are constants depending on the kind of ray.

Now let us proceed to sketch the rules for building the Mendeleev table.

Hydrogen and helium: one layer with only one sub-layer, which may receive only two electrons. Why two? Because the spin may have only two values, relative to the nucleus of the atom, and because two electrons never occupy the same quantic state.

Each further sub-layer may receive four electrons more than the preceding, as it has new angular resources, so they are 2, 6, 10, 14, 18 and we do not go further as the heavy enough nuclei do not exist. So the second layer of electrons has a ceiling at 8 in two sub-layers: Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Fluorine, and Neon.

The third layer begins by the eight electrons in the two first sub-layers: Sodium, Magnesium, Aluminum, Silicon, Phosphorus, Sulfur, Chlorine and Argon.

Next comes a surprise, as instead of the third sub-layer, the first sub-layer of the fourth layer (spherical with max two electrons) begins to fill up, this gives an alkali, the Potassium and an alkaline earth, the Calcium. Then only fills up the third sub-layer of the third layer, this gives the ten “*transition*” metals: Scandium, Titanium, Vanadium, Chromium, Manganese, Iron, Cobalt, Nickel, Copper and Zinc.

52 Henry Moseley engaged for the World War, and was killed in 1915 at the Dardanelles.

Only then resumes the normal filling of the fourth layer: Gallium (under the Aluminum in the table), Germanium (under the Silicon), Arsenic, Selenium, Bromine, Krypton. They count well as six elements. And the odd surprise comes again with the first sub-layer of the layer 5: Rubidium, Strontium, then ten transition metals, etc. Next in the 5th row, at n° 58 begin fourteen lanthanides. ... Why? According to the cost of energy for filling up such theoretical sub-layer.

Open-Eyes:

- We have reported in Annex A a recapitulative table of the occupations of the electronic layers and sub-layers in the Mendeleev table, for the elements in their stable state, in non-ionized vapor.

The table stops after the last element with at least one stable isotope ⁵³: the Bismuth.

Beyond the Bismuth, no more elements exist with stable isotopes, only with more or less unstable isotopes. The reader has noticed that as we stopped so, the columns 5_3, 6_2 and 7_0 are still empty. The sub-layer 7s or 7_0 begins with the Francium (n° 87), which is an alkali; the 6d or 6_2 begins at the Actinium, transition metal as the Scandium and the Yttrium; and the sub-layer 5f or 5_3 begins at Protactinium. The series of 14 lanthanides begins with the Cerium and ends with the Lutetium. The series of 14 actinides begins with the Thorium and ends with the Lawrencium. The discussion is not yet clear cut to put the Lanthanum in the 15 lanthanides, and to put Actinium in the 15 actinides.

The sub-layer with 18 positions of electrons 5g or 5_4 was not found in the stable electronic states, but it receives excited states and occurs in rays that the spectroscopists have observed.

This table is copied from Hume-Rothery and Raynor, *The structure of metals and alloys*. The Institute of metals. Pp 14-16. One has noticed that the three elements giving good conductors, the group 1b, copper, silver, and gold, have only one electron in the peripheral layer. This property is still there in a metallic state: only one electron per atom in the conduction band; so this conduction band is only half-filled, that is the ideal condition for a good electric conductivity (and thermal conductivity, by the way).

Curious:

- Say! It is tedious to read, your table!

53 **Isotopes:** atoms where the nuclei have the same number of protons, but not the same number of neutrons. They do not differ by their chemical properties, only by the atomic weight (maybe by the nuclear stability).

Open-Eyes:

- This is why the chemistry is a so difficult and complicated science. Moreover, this table of orbitals, only valid for an atom alone, relates to a primitive stade of the theory, and cannot take into account the hybridizations between orbitals of neighbor atoms in a molecule or a crystal; though only these hybridizations can predict the tetrahedral symmetry of carbon, silicon, and germanium when they are bound in a crystal, a quasi-crystal, a glass, or a molecule.

On the **tunnel effect**, I had said the essential: in an electric contact, the electron crosses some air and the isolated oxides because they are very thin, hardly wider than the interatomic distances in the metal, and largely smaller than the phase⁵⁴ wavelength of conduction electrons; the electronic wave easily spans over such thin obstacles. Why this word “*tunnel*”? Like as if a tunnel was bored under this mountain, allowing some crossing through the potential barrier. Sure, a poor electric contact rises the impedance of the circuit, and consequently heats more than the remaining; there is a potential difference to pay to cross the contact for a given intensity.

Professor Castle-Holder:

- We are stuck. We must include a whole periodic table. The book is small, so we must split it into three parts.

54 **Phase wave:** We owe to Louis de Broglie (1892-1987) in the years 1923-1924, to have distinguished the group velocity v of the electron, always lower than c (celerity of the light), from the phase velocity, always supraluminal. Their product is c^2 . If the electron moves, its phase wavelength is h/mv , at non-relativistic speeds. Already calculated at § 2.1.5.

Group →	1	2	3	4	5	6	7
↓ Period							
1	1 H						
2	3 Li	4 Be					
3	11 Na	12 Mg					
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc
6	55 Cs	56 Ba	57 La *	72 Hf	73 Ta	74 W	75 Re
7	87 Fr	88 Ra	89 Ac *	104 Rf *	105 Db	106 Sg	107 Bh
				58 Ce *	59 Pr	60 Nd	61 Pm
				90 Th *	91 Pa *	92 U	93 Np

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4.1.2 Energy levels defined in a solid

Professor Castle-Holder:

- Our Curious still has no idea of the pattern of electronic energies in a solid in “permitted bands”, divided by “forbidden bands”. Instead of few extremely fine levels as in the pure elements in vapor, the solid metals, and all the crystalline solids have these levels widely enlarged by coupling into **energy bands**. A dielectric (isolating) crystal has its last occupied band separated from the next permitted band by a big gap of energy. A semiconductor as the high-purity silicon has a forbidden band, a gap tight enough that the thermal agitation from the room temperature may be enough to throw some electrons over, into the next permitted band. The germanium has a narrower gap, so its conduction is more dependent on the temperature. So the germanium is given up by the industry of the diodes and transistors – though it had begun with the germanium.

A true metal either has no gap as its conduction band is only half-filled – so are the copper and the aluminum – either has a narrow gap, depending on the overlapping of the bands according to the crystallographic directions. In this last case, the gap may be overcome by slight zigzags; this case is the most frequent. Examples: the iron, the calcium, the magnesium, etc.

As stated above on the influence of atomic number and charge of the nucleus in the same column of the periodic table, the more we step down into heavy atomic numbers, the stronger is the metallic character: the gaps shrink. In the column 4, the diamond is an excellent insulating material. The high-purity silicon is still insulating, but by adding a very few impurity, bringing either some electrons more – doping type n – either some deficit in electrons – doping type p – we make it a semiconductor. The germanium is definitely a more metallic element, and its thermal racing comes too easily. Heavier, the tin crystallizes preferentially in a metallic state than in diamond cubic. Some half-metals only conduct well the electric current in one direction. So is the bismuth in monocrystal, or some antimony-bismuth alloys with less 5% antimony.

Open-Eyes:

- Thanks for this recalling. One may add that graphite carbon only conducts well in its base plane where its valence electrons are widely delocalized, but is insulating in the perpendicular direction, between dense planes. The patterns of energy bands depend on the crystallographic directions. The polycrystalline graphite is

half-conducting: each grain conducts in its base plane, and the grain boundaries transmit from one crystal to another. Hence the carbon brushes, the carbon contact of the pantographs, the polycrystalline graphite electrodes for electrolyzing alumina.

Curious:

- You overdo! Indeed I already knew that the LEDs, the electroluminescent diodes that surround us and give us light rely on gaps of some electron-volts – 1,3 V to 3 V according to the emitted color – and that they light only when fed in the passing direction. I also know that none is made of silicon, but of more unexpected semiconductors, still in diamond-type lattice crystals. Here are the most usual makings:

Color	Wavelength (nm)	Threshold (V)	Semiconductor
Infrared	$\lambda > 760$	$\Delta V < 1,63$	gallium-aluminum arsenide (AlGaAs)
Red	$610 < \lambda < 760$	$1,63 < \Delta V < 2,03$	gallium-aluminum arsenide (AlGaAs) gallium phospho-arsenide (GaAsP)
Orange	$590 < \lambda < 610$	$2,03 < \Delta V < 2,10$	gallium phospho-arsenide (GaAsP)
Yellow	$570 < \lambda < 590$	$2,10 < \Delta V < 2,18$	gallium phospho-arsenide (GaAsP)
Green	$500 < \lambda < 570$	$2,18 < \Delta V < 2,48$	gallium nitride (GaN) gallium phosphide (GaP)
Blue	$450 < \lambda < 500$	$2,48 < \Delta V < 2,76$	zinc selenide (ZnSe) gallium-indium nitride (InGaN) silicon carbide (SiC)
Purple	$400 < \lambda < 450$	$2,76 < \Delta V < 3,1$	
UV	$\lambda < 400$	$\Delta V > 3,1$	Diamond (C) aluminum nitride (AlN) aluminum-gallium nitride (AlGaN)
White	<i>Hot to cold</i>	$\Delta V = 3,5$	

Open-Eyes:

- Thanks for being so active!

The electronic specialists also noticed that even for emitting in the infrared, the LEDs have a tension threshold well above the one of the germanium, 0.3 V, and even of the silicon, 0.7 V. So, at least one craft is warned of occupations of solids by electrons, in permitted bands separated by forbidden bands. “Band” is here far from any geometric meaning, it is only related to the Cartesian graph energy x occupation.

Professor Castle-Holder:

- I correct Mr. Curious: When there are two or more alternating elements, as in the gallium phosphide GaP, the geometry of the diamond cubic lattice is re-named into “sphalerite cubic”. The mineral sphalerite is zinc sulfide ZnS. Moreover, not all the crystal lattices of this family are suitable to make a light-emitting diode: the energy of jumping must be emitted via a photon, not internally dispersed by phonons (elastic modes of vibrations). For more details about this physics, see the thesis from Daniel Ochoa:

<http://daniel.ochoa.free.fr/These/PageThese.htm> and especially

<http://daniel.ochoa.free.fr/These/AnnexA.PDF>.

Remember that a direct gap is necessary; « direct » means in the same crystallographic direction, while the silicon has only an indirect gap, with changing of crystallographic direction, so cannot emit a photon.

Open-Eyes:

- I am disappointed that this author (Ochoa) does not clearly precise the said crystallographic directions of the direct jump. Perhaps finding elsewhere? Slightly less deceiving is the Ashcroft & Mermin⁵⁵ who quote the original publication from Hogarth, 1965, to which to report for a more detailed legend of the figures. The direction [0 0 0], I still do not understand...

Professor Castle-Holder:

- That is because you reason as a pure crystallographer! The families of straight line directions [1 1 1] or [1 1 0] are familiar to you, but here it is the wave vector of the electron.

Open-Eyes:

55 Neil W. Ashcroft, N. David Mermin. *Solid State Physics*. Harcourt Brace College Publishers, Saunders College Publishing, 1976.

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- It would imply with $[0\ 0\ 0]$ a null wave vector, a motionless electron. It does not fit with what we will see later: Fermi energies and Fermi speeds.

Curious:

- I do not follow you anymore. You have forgotten me.

Open-Eyes:

- Your objection is justified. We were just reaching the Fermi level of the electrons in a solid.

In this domain of the physics of the semiconductors, there is no difference between the calculations by the transactional microphysics and by the standard MQ. However, the semantics still strongly differ. Example: “*As the impurity is very localized in space, according to the Heisenberg principle of uncertainty, the uncertainty on the momentum of the trapped electron is very high*”, page 263 in the thesis of Daniel Ochoa. Now I correct him: As the impurity is very localized in space, the properties of the Fourier transform induce a high indefiniteness of the momentum of the trapped electron.

Open-Eyes:

- Another surprise for the general public: in crystallography as in electromagnetism, I have used concepts and notations which are not those taught as standard: **outer projection, inner projection, inner product, outer product, equiplane**. I will not re-do the course here; I direct you to the course online:

http://deontologic.org/geom_syntax_gyr .

An equiplane is the equivalence class of the planes with the same plane direction. As for now, remember that neither the magnetic field \vec{B} , nor the moment of a force, nor a spin are vectorial quantities, but are gyratorial quantities. The vectorial quantities have a straight line direction, and a sign of displacement along this line direction; though the gyratorial quantities have a plane direction (an equiplane) and a sign of rotation in this equiplane. Their symmetries are opposite, and their dimensional behaviors oppose them too. As a result, no “*magnetic monopoles*” may exist, the *hedge-hogs theorem* forbids it: it is impossible to entirely comb a hairy sphere.

Fermi energy levels: The Fermi level is the uppermost of the occupied positions by the electrons of a metal. It is at 7 eV (above the most bound level) in the copper, at 5,48 eV in silver, at 11,63 eV in aluminum. For the aluminum, the

Fermi speed, which is the group velocity of each conduction electron in the metal, is $2.02 \cdot 10^6$ m/s or 2,020 km/s, measured at the room temperature. 6.7 thousandths of c , it is not usually considered as a relativistic speed, while the phase velocity is highly supraluminal.

Curious:

- Something is wrong in your affair: I have practiced electrotechnics, and I know that at the densities of current we handle, an electron does not progress more quickly than a ten of micrometers per second!

Open-Eyes:

- Indeed. It is the average drift, bouncing back from obstacle to obstacle. Be conscious that in metals, the conduction electrons are those with the highest energies, the less bound to each metallic ions of the crystal.

Curious:

- And what are these obstacles that make electrons bounce back like a flipper ball?

Open-Eyes:

- I fear it will drive us very far. Too far?

Curious:

- You are already so far into the too far...

Professor Castle-Holder:

- Before turning the page, let's give the reader an exercise to do. In any popularization videos, the general public has seen a planet-electron orbiting around a central star-nucleus. So it would have the symmetry of a turn, with a plane of turn, and an orbital moment in this plane. However, solving the Schrödinger equation gave for the fundamental solution a fuzzy sphere, without any orbital moment. When you dare to question them, the high priests of the corpuscularism reply that this orbital plane does not stop to change, so that in the long term, no trace of it subsists.

Your mission, if you accept it, consists to conjecture the physics of this ever-changing plane. Good courage!

And you are not over, as at best so you may obtain a neat sphere, like a ping-pong ball. But to obtain the radial density given above by exactly solving the

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Schrödinger equation – which is widely confirmed by experimental results - your mission is indeed impossible.

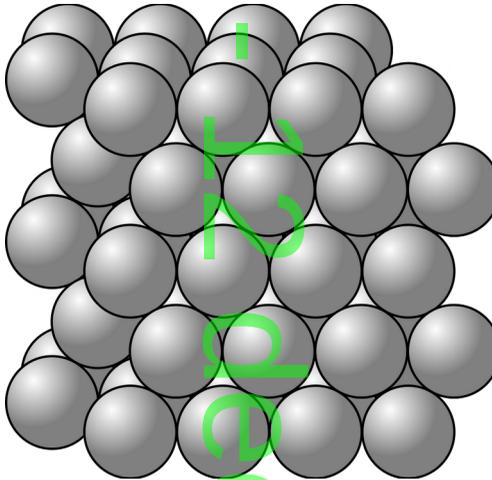
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4.2 The metals and their crystalline arrangement

Open-Eyes:

- Here we will see the impurity atoms which disturb the regular arrangement of the atoms in a perfect crystal, the dislocations, the grain boundaries, and the phonons, these quantified thermal agitations of the crystal, according to the temperature. We will not see the plasmons and polaritons here; only much later, when we will revise the photoelectric effect in chapter 11.

The general public has not precise ideas on the crystalline arrangements, so here is an image of a compact hexagonal, drawn as an assembly of hard balls; it is the lattice of zinc, cadmium, beryllium, magnesium, titanium:

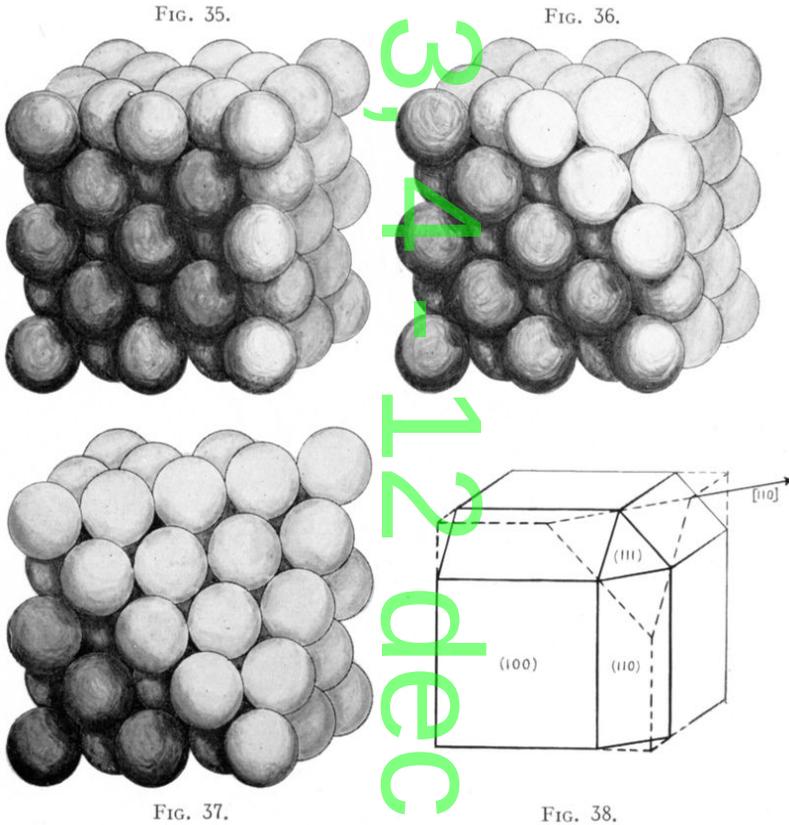


The plane of the sheet of paper is a compact plane: it represents the hexagonal plane where the “balls” occupy the plan at best. The horizontal and at 60° rows are compact straight directions. You may observe a similar compact plane on market stalls, for presenting the oranges.

In compact hexagonal, the successive planes are in the sequence **ababab**, etc. But many other metals have another compact sequence, with higher symmetry,

said face-centered cubic or fcc, where the sequence of the compact planes is **abcabcabc**, etc. So is the case of all the coinage metals and good conductors, gold, silver, copper, aluminum, but also nickel, platinum, strontium, and also the iron between 914°C and 1360°C, and austenitic⁵⁶ stainless steels containing nickel, the Hadfield steel containing manganese, used in the point rods, crossing frogs, and rivet setters.

Figure 4.8.



FIGS. 35–38.—Unit Cell of Face-Centered Cubic Structure.

56 **Austenite** or gamma iron is face centered cubic. This lattice may be stabilized at room temperature by additions of carbon, nickel, manganese, nitrogen, copper, zinc, said gammagen elements, which increase the stability domain of the austenite.

Certainly, these drawings are due to William Hume-Rothery, as they were in *The Structure of Metals and Alloys* published by The Institute of Metals.

The cobalt is usually indecided between hexagonal and cubic stacking and may present any variants mixing **ababab** with **abcabc** stacking orders. Otherwise, many metals crystallize in a less compact lattice, said body centered cubic (bcc): all the alkalis, the iron above 1400°C or under 914°C (but it is unique: because it is ferromagnetic at low temperature), vanadium, niobium, tantalum, chromium, molybdenum, tungsten, barium.

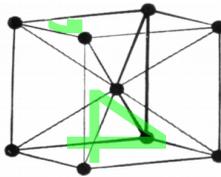


FIG. 39.

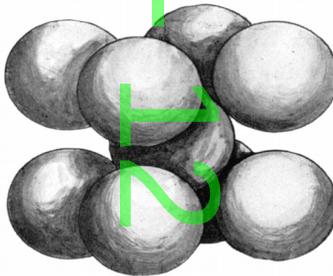


FIG. 40.

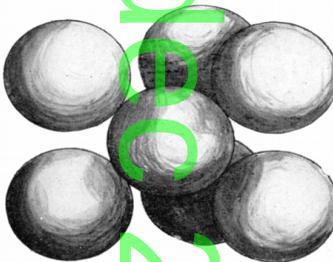


FIG. 41.

Figs. 39-41.—Unit Cell of Body-Centred Cubic Structure.

Figure 4.9.

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All these images with hard balls sacrifice to the ease of drawing. In the real world each atom reshapes and attracts the electronic clouds of its neighbors, so these electronic clouds compose a three-dimensional continuum. However, the image they give of the interstitial spaces is rather faithful. The interstitial sites in fcc are much larger than in bcc.

Curious:

- And again lots of new words! Dislocations, phonons, grain boundaries?

Professor Castle-Holder:

- First, we will make up a lateness: the ferromagnetism is a state where all single electrons unite to align their spins in the same equiplane in a magnetic domain.

In ferrimagnetism, there is a majority population of spins and a minority. On the bulk, the majority wins, by large. The ferromagnetism occurs in iron and some alloys. The ferrimagnetism occurs in oxides and ceramics, whose the first known was the magnetite Fe_3O_4 .

Open-Eyes:

- From the metallurgist point of view, a point is of importance: at room temperature, the iron is totally magnetized, but in small looping and closed domains which compensate each other in bulk. There are directions of preferred magnetization in the crystal, and ones have proved by electronic micrographies by transmission stripped patterns, by alternation between two preferred orientation, each approximating the externally imposed field. In machinery of electrotechnics, which are naturally macroscopic, the boundaries of the magnetic domains move when externally solicited. Less compact, the body-centered cubic lattice is a high-temperature allotropic form. Only the ferromagnetism explains the unexpected stability of the body-centered cubic iron at low temperatures.

Curious:

- However, The Curie point of pure iron is 770°C , far below the transition of gamma iron to alpha iron, that occurs at equilibrium at 914°C . A 144° difference! How do you explain such a lacuna in your explanation?

Open-Eyes:

- The Curie point is from our macroscopic point of view, and is a mass effect: The Bloch boundaries between magnetic domains do not spontaneously move under the Curie temperature. Between 770°C and 914°C they are moving and fluctuating, at a rhythm far beyond the human experimental means, up to now; so

we cannot obtain any macroscopic magnetic polarization; however this is enough to stabilize the alpha phase. Anyway, at cooling, the kinetics of the transformation of gamma iron to alpha iron is slow, as governed by the migration of the interstitial carbon atoms. This slowness allows the quenching of the steel, in numerous variants.

Curious:

- Dislocations? Phonons? Grain boundaries?

Open-Eyes:

- First, let us talk impurities: when you buy copper for its electrical conductivity, you pay it more dearly than copper for water or gas pipes, as you need high purity, with very, very little interstitial oxygen. This copper for conduction is carefully deoxidized. If you asked me the detail of the drawbacks of oxygen and different impurities for conductivity (and mechanical properties) in copper, alas I could not answer. But it is more complex than "*it obstructs the channels*". The conduction electrons are the less bound, the freer. In pure copper, their mean free path is about a hundred interatomic distances, and it lengthens at low temperatures. Add nickel, and the mean free path decreases: this atom has not the same diameter, nor the same electronic affinity, nor the same electronic charge. Few metals are good conductors, only those with one electron per atom in the conduction band: gold, silver, copper, aluminum. The alkalis, lithium, sodium, potassium, are very soft and flammable, so not usable.

The other imperfections in the metal are unfavorable to conduction too. The grain boundaries are the contact surfaces between crystals; in fact, our metals for technical usage are polycrystalline. The exception are some blades of turbo-reactors, which are monocrystalline to avoid the intergranular creep at high temperature.

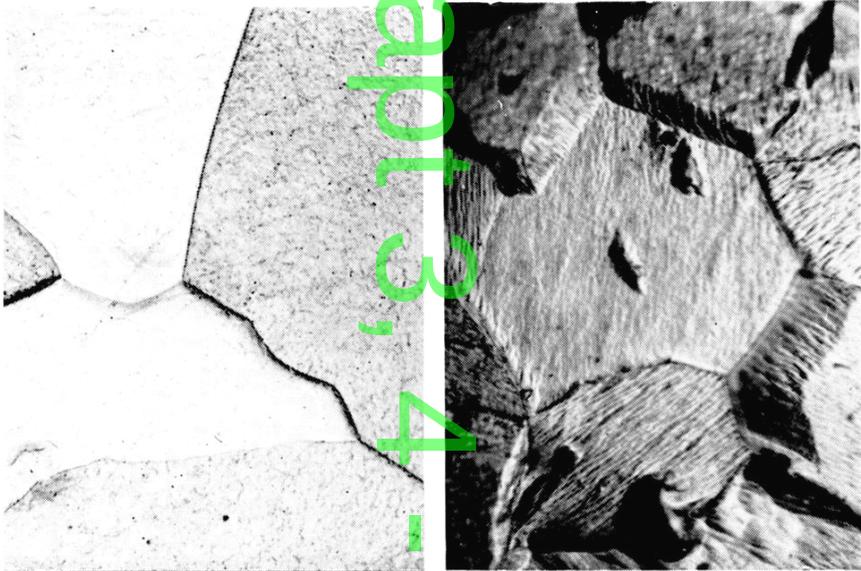


Fig. 192a. $\times 25$. Fig. 192b. $\times 1000$.
 Fer très pur résultant de la fusion par zone; impuretés totales = quelques p.p.m. Attaque poussée d'un fer industriel.
 (comparer les grosseurs de grain : $\times 25$ d'une part et $\times 1000$ d'autre part).

Figure 4.10.

Only the relative scales are conserved by the reproduction. Extracted from *Traité de métallurgie structurale*, by DE SY and VIDTS. They are optical micrographies, on a metallography microscope.

The most often, the grains, or elementary crystals, have a size in the one micrometer to ten micrometers range, so often under the separating power of an optical microscope. By annealing, one can make the grain grow: the most perfect grain grows at the expense of the less perfect ones, as the *good crystal* has a lower internal energy than the *good crystal*, and more than the grain boundary. Next we have an electronic micrography by transmission through a thin plate.

The arrows point on the dislocations which cross the thickness of the thin plate.



FIG. 246. — Micrographie électronique d'une lame mince de cuivre électrolytique laminé de 99% et recuit 7 heures à 78 °C. Les blocs A, B, C, D, d'orientations très voisines sont en cours de coalescence; certaines dislocations provenant de la désagrégation de la limite entre A et B, se déplacent vers la frontière externe du nouveau bloc (d'après Mme Bourelier)

Figure 4.11.

Extract from *Métallurgie Générale*, by Bénard, Michel, Philibert and Talbot.

High purity aluminum, this one which has good resistance to corrosion by the quality of its adherent alumina layer, but is too soft for most technical uses, has grains about half a millimeter, so you see them all buckle differently (according to their crystalline orientations of easy slip) when you proceed a traction proof. And

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finally, some metallic crystals are so large as you can see them with naked eye: those of a thin covering of zinc on electrogalvanised mobile barriers or on the poles for urban lights, or for street signals. This photo, anyone can do it:



Figure 4.12.

When you sollicit a metal in the plastic domain, it buckles by creating and circulating dislocations, which are linear defects in the metal. Here you have a modelisation with rolls:

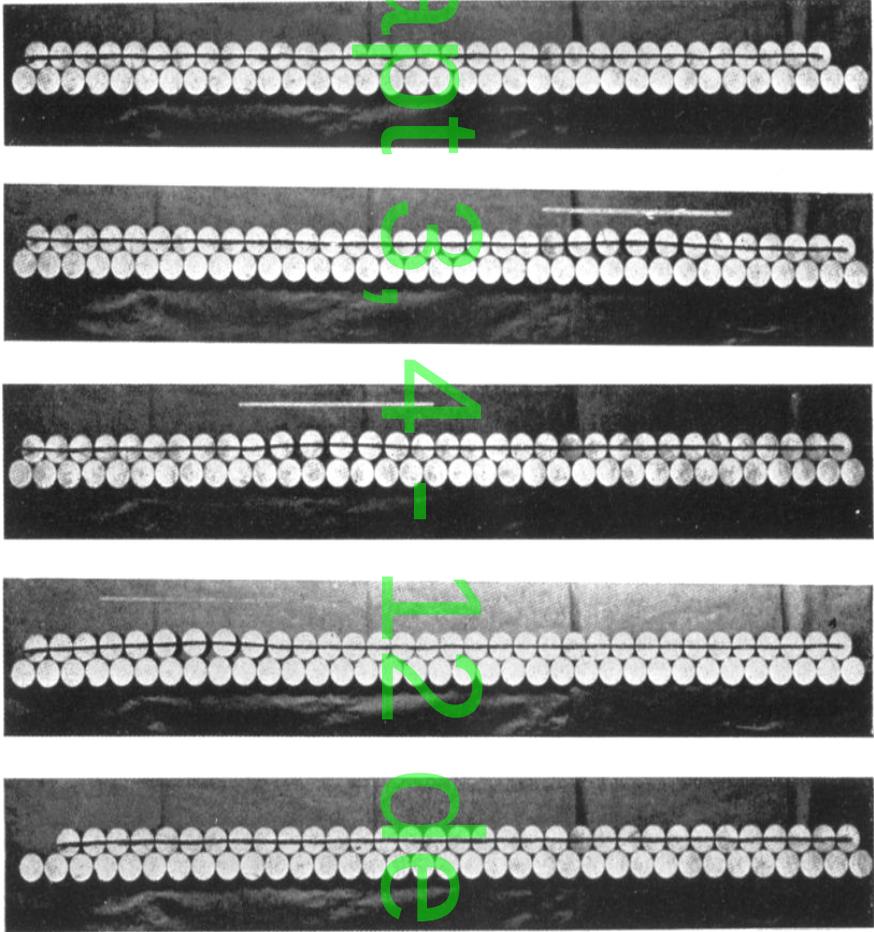


FIG. 235.—Representation by Means of a Series of Rollers of Dislocations Travelling Across a Crystal Plane. (After E. N. da C. Andrade.)

Figure 4.13.

Next comes an electronic micrograph by transmission in an aluminum alloy of type duralumin. The dislocations are the dark spirals (dark as less transmitting the incoming electrons, maybe dispersing them).

Figure 4.14.

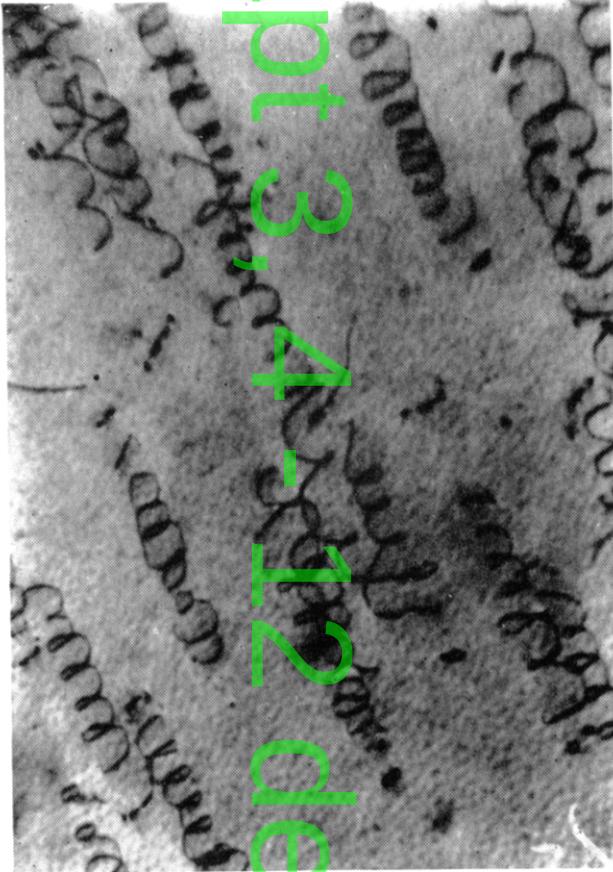
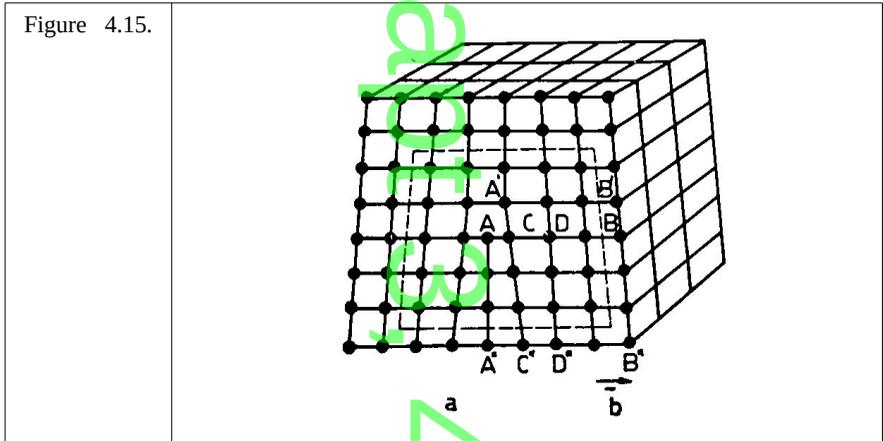


FIG. 279.—Aluminium-3% copper alloy quenched from 550° C. into water at room temperature. $\times 20,000$.
(Westmacott, Hull, Smallman, and Barnes.)

The edge dislocations are the boundary of a half-plane, existing at the right, and not at the left (if you prefer, under but not above).



The screw dislocations are like a helix staircase. Fig 4.16.

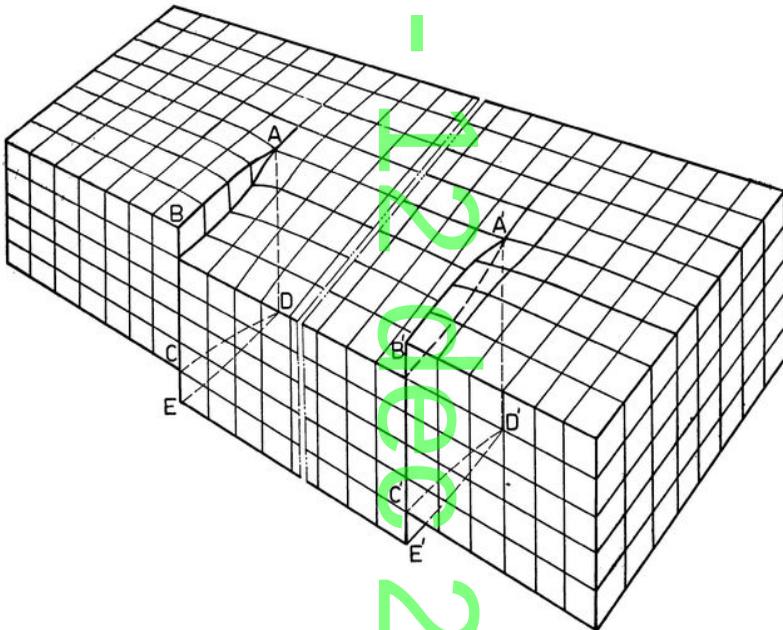


Fig. 30. Dislocation vis.

Cold-formed metal, having been deformed by plastic work without heating, are less conducting than an annealed metal. Unlike what happens when you crush granite, the crystals of a polycrystalline metal remain bound together in the plastic deformation; the metallic bond and the metallic state remain through the grain boundaries. The metallic bonds are very little oriented.

Curious:

- Please do as if we did not know what a metallic bond is. Please recall that!

Open-Eyes:

- There are three kinds of strong chemical bonds and two weak ones.

1. The **electrostatic bond** is the most simple to understand. It bonds the Cl^- anions to the Na^+ cations in the kitchen salt. Or it bonds the cation Ca^{++} to the anion SO_4^- in the neutral molecule CaSO_4 , a not negligible neutral ion in the sea water, strong ionic solution.
2. The **covalent bond**, or the homopolar linkage as in the diamond, and in all the carbon-carbon bonds in the organic molecules of our body. It is due to the sharing of a pair of two electrons, with opposite spins, and so with opposite magnetic moments. Similarly, the gaseous molecules of our atmosphere dinitrogen, dioxygen, or the molecule dihydrogen, the macromolecules of the molten sulfur, etc. These linkages are space-oriented, see for instance the four tetrahedral bonds for the carbon in the organic molecules.
3. The **metallic bond** is not or almost not space-oriented. The metallic atoms loosely hold their peripheral electrons, those with the highest energy, so they are shared by the whole solid, crystalline or amorphous. The metallic ions pack together in an arrangement as compact as possible, preferably compact hexagonal or face-centered cubic, but maybe body-centered cubic, according to the available orbitals and valencies. The electronic gas is mobile enough to conduct the electric current, conduct the heat, reflect the light, etc.
4. Mostly occurring in organic molecules and macromolecules, the **hydrogen bond** is the sharing of a proton H^+ between two electronic clouds. From the hydrogen bond come the mechanical resistance of the collagen of our skin and bones, of the leather, and of the polyamides. It is also the basis of the “abnormal” properties of liquid water and ice, and of the liquid ammonia.
5. The weakest of all is the **Van der Waals bond**. It is of electrostatic nature, but quadrupolar, so only at very short distances and dependent on

the flabbiness and plasticity of the macromolecules, apt to tightly model together. It is responsible for the resistance of the polypropylene and of the polyethylene, and anybody knows how they are very modest. One knows less that their efficiency depends much on the molecular weight, which must be high. So to have a useful material, you must obtain micelles as large as 400 \AA or higher for their long axis.

Now the typology is set, most of the real cases are hybrids. In the silica, or in the alumino-silicic skeleton of the feldspars, the bond is partly covalent and partly electrostatic. In the silicon, the bond is partly metallic and partly covalent, and more metallic in the more conducting germanium; both crystallize in the diamond cubic lattice. In molecules with differing atoms, like CO and CO₂, the bond is not purely covalent, but partly electrostatic – so these molecules may couple their vibrations with resonating infrared photons. In all the *at-the-disposal-of-the-oligarchy* press, you endure lots of bombarding by *tall stories* and political extravagances on the capture of two infrared frequencies by the molecules of the atmospheric CO₂, to obtain your terror, and to submit you in full panic at the disposal of the bankster oligarchy.

About the phonons, they are individual waves of vibration or thermal agitation. They also exist in minerals, glass, and ceramics. The waves undulating on the crops by the wind give a good idea of them. Think of the irish song: *The wind that shakes the barlow*. In these materials, the thermal conductivity and the thermal capacity is due only to phonons. In the metals, the conduction electrons intervene more and are dominating. At room temperature in copper, the mean free path of an electron before it is blocked and thrown back by a phonon is about 200 \AA . The most you cool a metal and the most its conductivity increases: there are fewer phonons, and the mean free path lengthens.

Moreover, some materials have the property of superconductivity, if the temperature is low enough: a wave associating two electrons with a tuned phonon runs freely without seeing any obstacle, and the resistivity drops to null. A phonon is always sampled on several atoms, many atoms, and never can become small. It is one of the reasons which compelled us to understand that a conduction electron never may become *small*; each one is several interatomic distances large, even several tens of interatomic distances. Even wider at low temperatures.

Curious:

- Unbelievable! It seems impossible. So your electrons are individually as big as a thousand atoms? Each?

Open-Eyes:

- Some more precisions for the conduction electrons in the copper at room temperature: the Fermi group velocity is 1,570 km/s, corresponding to 7 eV, the phase velocity is $57.2 \cdot 10^9$ m/s. On a free path of 200 Å (20 nm), so a duration of 12.7 fs (femtoseconds), the phase wave runs 0.738 mm; while the wavelength of this electronic phase is 4.6 Å. The spatial extension of this electron is about the same magnitude: few tens to several hundreds ångströms. At each end of this propagator, there is an interaction with the more frequently a phonon, or a distortion of the lattice such as dislocations, lacunae⁵⁷, impurities⁵⁸. Each electron occupies several tens of interatomic distances.

So they are not balls, they are not solids, nothing common with our familiar objects around us. Each one remains a wave, an electronic wave. Nothing holds them from occupying, simultaneously many, the same space which does not have the same features than our familiar macroscopic space (where only one solid occupies its own space). In the real microphysical world, so little familiar to the layman, the only constraint on the electrons is that they do not occupy the same quantic state, as stated by the exclusion principle from Pauli: the electrons have a ½ spin, so ruled by the Fermi-Dirac statistics.

And worse: it has been proved that obviously composed objects, such as protons, neutrons, helium atoms, fullerenes, and even insulin molecules, behave as their de Broglie waves, and are diffracted just like photons. It poses a serious problem in understanding what becomes our familiar geometry when extended to microphysics. My colleague was not trained to suspect this geometry, though we strongly suspect it.

Curious:

- Say! They are not big, your impurities you have accused to punch away or back the conduction electrons! So, to collide these small impurities, are your conduction electrons compelled to shrink to become as small as the stranger atom?

Open-Eyes:

57 **Lacuna:** an atom is lacking in the crystalline lattice.

58 An **impurity** in a crystal may be an atom substituted in the lattice, for instance, a zinc instead of a copper atom, or an insertion, like carbon or nitrogen in the interstitial sites between the regular atoms (used in carbo-nitridation of the steels for gears teeth). Frequently they concentrate on the grain boundaries.

- The premise of your reasoning is almost true: as it differs in size from the substituted atom, or as it is inserted, the impurity atom elastically distorts the crystalline lattice, up to two to three times its diameter around. Moreover, if it has a different valency, like zinc or tin in copper, it locally changes the electronic state, mainly the electronic density and the electron affinity. The impurities also block the run of the dislocations; so the use of alloys to obtain much more hard metals which at pure state would be far too soft (too plastic) to be useful. Examples: copper-tin, or bronze, copper-arsenic when tin is lacking, iridio-platinum, iridiogold, manganese-carbon-iron, etc.

Professor Castle-Holder:

- Would you give some exercises to the reader?

Open-Eyes:

- This time, I break the tradition: not a calculus exercise, but a documentation exercise. It is up to the reader to collect documents on the structural hardening of duralumin, alloy with 4% copper and a few magnesium (AU4G in AFNOR norm). Both aluminum and copper crystallise in face-centered cubic when pure, but their cell parameters slightly differ. The trick is a thermal treatment which efficiently blocks the run of the dislocations. It is up to the reader to find and compare these parameters, and to find which is the thermal treatment producing this optimal hardening. "Hardening" does not imply a change in the elastic constants, but hindering the beginning of plasticity.

In balance to the increased mechanical properties, which opened a wide use in aviation, the duralumin has a poor resistance to aqueous corrosion, especially with marine water. The Alclad is a co-rolling: pure aluminum, then duralumin, next pure aluminum.

Professor Castle-Holder:

- I do not agree with your breaching the tradition. I give this elementary exercise: Given that the body-centered cell contains 2 atoms, that the cell-parameter of the iron is 2.856 Å, and that the average molar weight of the iron is 55.85 g, calculate the theoretical density of the pure iron, supposing it is only good crystal, without lacunae nor dislocations. The Avogadro constant was given earlier.

That very pure iron has no technological use: it is far too soft. Excepted maybe for anticathodes for radiocrystallography of the phyllosilicates; it has only some scientific uses, in some laboratories of solid state physics. It costs more or less as dear as gold.

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