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THE PHOTO-ELECTRIC EFFECT
OF
FINELY DIVIDED CARBON
AND
CERTAIN OTHER SUBSTANCES

Thesis for Degree of M. S.
Wesley E. Thomas
1927

HISTORY OF PHOTO-ELECTRICITY

The first important observation of photo-electricity was that of Hertz in 1887, when he found that a spark would pass between two plates more easily if the negative plate was illuminated by the light of another spark. This effect led Hallwack, Elster, Gertel and others to experiment with metal plates and they found that negatively charged plates lost their charge when they were illuminated by a suitable source of light. In 1896 Sir J. J. Thomson explained the nature of the conductivity imparted to gases by various agents, especially x-rays and thereafter made very rapid progress in the investigation of photo-electricity and conduction through gases. Then Sir J. J. Thomson and Lenard observed that a metal plate in a vacuo would emit electrons if illuminated by ultra-violet light. These electrons have a velocity of 10^7 cm/sec., while those of the cathode rays have a velocity of 10^{10} cm/sec., showing that the electrons observed by Thomson and Lenard were slower than electrons of the cathode ray.

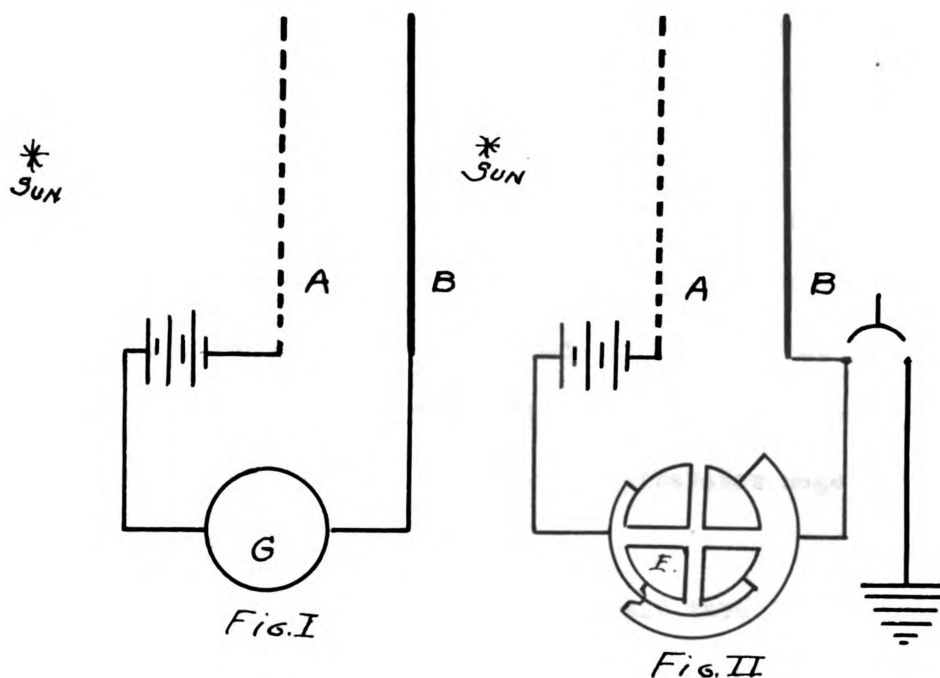
1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that proper record-keeping is essential for transparency and accountability, particularly in financial matters. The text suggests that organizations should implement robust systems to track every aspect of their operations, from procurement to sales.

2. The second part of the document addresses the challenges of data management in a rapidly changing environment. It highlights the need for flexible and scalable solutions that can adapt to new technologies and evolving business requirements. The author argues that investing in modern data infrastructure is crucial for staying competitive and making informed decisions.

3. The third part of the document focuses on the role of leadership in driving organizational success. It stresses that effective leaders must be able to inspire and motivate their teams, while also providing clear direction and support. The text provides several practical tips for developing strong leadership skills, such as active listening and open communication.

4. The fourth part of the document discusses the importance of continuous learning and development. It notes that in today's fast-paced world, employees must constantly update their skills and knowledge to remain relevant. Organizations are encouraged to create a culture of learning that supports ongoing education and professional growth.

5. The fifth part of the document concludes by summarizing the key points discussed and offering final thoughts on the future of business. It reiterates the importance of innovation, collaboration, and resilience in achieving long-term success. The author expresses optimism about the potential for growth and progress, provided that organizations continue to embrace change and innovation.



Stoletow produced some evidence of photo-electricity when he performed the following experiment. He had a solid plate "A", Figure I, and a perforated plate "B" and a very high resistance galvanometer of high sensitivity. He had a source of potential, the negative of which was connected through the galvanometer to the plate "A" and the positive to the plate "B". He found that when the plate "A" was illuminated the galvanometer indicated a flow of electricity, but this was not so if the connections were reversed. He also made a photo-electric cell which supplied a current to the outside by its action. A solid plate "A", Figure II, was used and a perforated plate "B" and a quadrant electrometer was used in place of a galvanometer. Stoleto found that if he allowed

ultra-violet light to pass through the openings in the perforated plate that current would flow. He used the sun as a source of light. The conclusions of Riche, Stoletow and Arrhenius were not quite correct. They believed that the current produced was due to the contact difference of potential between the plates and the air between the plates and dielectric which made the two plates the same potential. This difference in potential must be considered, but the main action is due to the light, which liberates negative charges from the illuminated plate.

Very little was published until 1898 and then the articles were scattered and not until about 1910 did photo-electricity become popular among physicists. In 1906 H. S. Hower performed experiments on "The Production of Ozone by a Photo-Electric Current". Ultra-violet light was allowed to fall upon a polished platinum knob in an oxygen atmosphere. The knob was charged to a negative 1500 volts, and the discharge current, from it to the earth wires opposite the knob, was measured by a galvanometer in series. The ozone produced was detected by its effect on a piece of platinum foil. The foil changed its position in the voltaic series when it absorbed ozone. In 1908 W. F. Holman contributed data on "Fatigue and Recovery of the Photo-Electric Current". The same year F. K. Richtmeyer contributed data on "The Dependence of the Photo-Electric Current on Light". In 1910 Millikan proved, to his own satisfaction, Einsteins

equation for the "Emission of Electrons". Then in 1914 J. Robinson investigated "The Velocities of the Electrons Emitted". He found that for very thin films (less than 10^{-7} cm) the maximum velocity of emission due to the emergent light was greater than that due to incident light; for thicker films the reverse was found to be true, since the maximum energies of emission are independent of the illumination. Partzsch and Hallwachs concluded that the variation in absorption of the two positions of the films would be no adequate explanation of this observed change in velocity. Robinson also determined distribution of velocity curves for four samples of different thickness of films.

Since 1916 the field has had many contributions on photo-electricity, but very little on finely divided carbon and for that reason I am trying to offer some data concerning "Finely Divided Carbons". In addition I am reporting some of my results on the photo-electric activity of certain dyes.

PHOTO-ELECTRIC ACTION

In photo-electricity we are dealing with electrons, but because of their connection with this effect they are called Photo-electrons; however, they differ in no way from other electrons. The difference pertains to the method of liberating them, and yet even here, there is a marked similarity. Ordinary electrons are liberated from gaseous and liquid matter while photo-electrons are liberated

from solid matter. Rutherford advanced the theory that the atom itself is a complex system built up of a positive nucleus of great complexity carrying a positive charge, which is surrounded by a number of electrons, each carrying negative charges; the atoms differing according to the element.

With this in mind we seem to be able to classify electrons as follows:

1. Free electrons to which the electrical conductivity of metals is due.
2. Dispersional or Emission electrons which give rise to the absorption of light and are responsible for the Zeeman effect.
3. The valency electron which corresponds to the chemical bond.
4. The Photo-electrons which are separated from the atom by the influence of light.

The second and third are identical and when an absolute classification is made, probably all electrons are identical, but the task here is to prove that the photo-electron is also a member of, and identical with, the other three.

It might be well to review some of the previous works on this subject. The work of Pohl and Pringsheim certainly suggests that the electrons of the selective effect are connected with the chemical binding of the atom. According to the theory of Stark also, the

electrons of the photo-electric effect are the valency electrons. Lenard distinguishes between the photo-electric electrons and the emission electrons, and on this distinction bases his theory of phosphorescence. The excitation of a phosphorescent substance by light consists in the separation of the photo-electrons. These on their return to the atom set in vibration the emission electrons, so giving rise to the luminescence. This theory is not well founded as the initial velocity is independent of the intensity of the light. Lewis and Langmuir have developed a very suggestive theory as to the geometrical arrangement of the electrons in atoms. Assuming with Rutherford that the positive charge of the atom is concentrated in an exceedingly small nucleus, it is supposed that the electrons are distributed through a series of concentric spherical shells; the effective radii of the different shells stand in the ratio $1:2:3:4$ and the effective surfaces are in the ratio $1:2^2:3^2:4^2$. In the Rutherford-Bohr theory of atomic structure the atom resembles a planetary system in which the planets are electrons, which circulate about the central positive charge or nucleus. The electrons may be divided into a number of groups which, in the earlier presentation of the theory, were regarded as shells enclosing one another. In his latest investigation (which will be discussed later) Bohr regards a "shell" as a closely bound group of electrons although each individual electron can at times approach the nucleus, or recede to an infinite distance from it. We may, however, distinguish between

the "peripheral" and "central" properties of the atom. Thus the X-ray spectrum has its origin in the innermost orbits of the atom, while the optical spectra are produced at the periphery. The electrons which are liberated by ordinary light come from the periphery of the atom, and are those responsible for its chemical behavior.

Let us next ask how the electrons escape from the surface of metals or any other surface, under the influence of light. Several theories have been advanced to explain this liberation, and difficulties have been found in most all theories. The corpuscular theory of light seems to offer a solution. These tiny particles striking against the plate at a very high velocity will disturb the atomic balance and electrons are emitted. The difficulty encountered here is that we have no well defined foundation for the corpuscular theory. Another theory for this liberation is the "explosion" theory. Again we assume that the complex atomic system is unstable. The theory is that photo-electrons being in an unstable condition are completely thrown off balance by the action of the short wave lengths of light. If this is the case the energy of the escaping electrons is derived from within the system, thus the photo-electric effect would be similar or equivalent to an induced radio-activity. This, however, cannot be so because we have experimental evidence that radio-activity is entirely independent of all external conditions. Another theory is that the electron is liberated because of the velocity

- **Einfluss von Umweltfaktoren:**
 - **Temperatur:** Beeinflusst die Geschwindigkeit der Enzymreaktionen. Hohe Temperaturen können Enzyme denaturieren.
 - **pH-Wert:** Beeinflusst die Ladung der Aminosäureketten und damit die Struktur des Enzyms.
 - **Salzkonzentration:** Hohe Salzkonzentrationen können die Löslichkeit von Enzymen verringern.
- **Enzymaktivität:**
 - **Definition:** Die Fähigkeit eines Enzyms, eine chemische Reaktion zu katalysieren.
 - **Einflussfaktoren:**
 - **Substratkonzentration:** Erhöht die Reaktionsgeschwindigkeit bis zu einem Sättigungspunkt.
 - **Enzymkonzentration:** Erhöht die Reaktionsgeschwindigkeit linear.
 - **Temperatur:** Erhöht die Reaktionsgeschwindigkeit bis zu einem Optimum.
 - **pH-Wert:** Beeinflusst die Enzymaktivität über den isoelektrischen Punkt.
- **Enzymkinetik:**
 - **Michaelis-Menten-Kinetik:** Beschreibt die Beziehung zwischen Substratkonzentration und Reaktionsgeschwindigkeit.
 - **Michaelis-Menten-Gleichung:**

$$v = \frac{V_{max} \cdot [S]}{K_m + [S]}$$
 - **Michaelis-Menten-Parameter:**
 - V_{max} : Maximale Reaktionsgeschwindigkeit.
 - K_m : Michaelis-Konstante, die die Substratkonzentration bei halber V_{max} angibt.
- **Enzymregulation:**
 - **Allosterische Regulation:** Beeinflusst die Enzymaktivität durch Bindung von Effektoren an allosterische Stellen.
 - **Kovalente Modifikation:** Beeinflusst die Enzymaktivität durch reversible oder irreversible chemische Veränderungen.
- **Enzymnomenklatur:**
 - **Enzymklassen:**
 - **Oxidoreduktasen:** Katalysieren Redoxreaktionen.
 - **Transferasen:** Übertragen funktionelle Gruppen.
 - **Hydrolasen:** Katalysieren Hydrolyse-Reaktionen.
 - **Ligasen:** Katalysieren die Bildung von chemischen Bindungen.
 - **Isomerasen:** Katalysieren Isomerisierungen.

given to it by the passage of a half-wave of light. The kinetic energy of the emitted electron is derived from the energy of the incident light. The difficulty here is, the magnitude of the initial velocity is too large for it to come from a half-light vibration. Further the velocity of emission is independent of the intensity of the incident light. We know from experiments that the photo-electric effect is instantaneous. If the emitted electrons obtained their velocity from a spreading wave-front the photo-electric effect would not be instantaneous but some time would elapse before the action could be detected. This is true because a spreading wave-front could not impart all the energy to the electron, all in a lump and cause instantaneous action, but the energy would be imparted to the electron in very small increments and the accumulation of these increments would cause the photo-electric effect. Again the resonant vibration has been suggested as a possible explanation of this phenomenon. The electrons are set into vibration by incident light and thus acquire sufficient energy to enable them to escape. If light of the same frequency is incident upon the electron so as to excite linear resonance vibration, the amplitude of the vibration will go on increasing until its magnitude becomes sufficient to free the electron from the atom. However, under these conditions its velocity would be zero. In order that the electron might leave the atom with finite velocity it must obtain its energy from the last half of the

1. The first step in the process of the scientific method is to ask a question. This question should be based on observation and should be specific and measurable. For example, "Does the amount of sunlight affect the growth of a plant?"

2. The second step is to do background research. This involves looking up information related to the question to see what is already known and to help form a hypothesis.

3. The third step is to form a hypothesis. A hypothesis is a statement that can be tested. It should be based on the background research and should be specific and measurable. For example, "If a plant receives more sunlight, then it will grow taller." This is often written in an "if-then" format.

4. The fourth step is to design an experiment. This involves deciding what to test, how to test it, and what to measure. The experiment should be designed to test the hypothesis and should include a control group and an experimental group.

5. The fifth step is to collect data. This involves recording the results of the experiment. The data should be organized in a way that makes it easy to see patterns and trends.

6. The sixth step is to analyze the data. This involves looking at the data to see if it supports the hypothesis. This can be done by comparing the results of the experimental group to the results of the control group.

7. The seventh step is to draw a conclusion. This involves stating whether the hypothesis was supported or not supported by the data. It also involves discussing any limitations of the experiment and suggesting further research.

8. The eighth step is to communicate the results. This involves sharing the results of the experiment with others. This can be done by writing a report, giving a presentation, or publishing the results in a journal.

9. The ninth step is to repeat the experiment. This is done to make sure the results are reliable and to see if the same results can be obtained under different conditions.

10. The tenth step is to apply the results. This involves using the results of the experiment to solve a problem or to make a prediction. For example, if the results show that more sunlight leads to faster growth, this information can be used to help farmers grow crops more efficiently.

The scientific method is a process that allows scientists to test their ideas and to learn about the world around them. It is a systematic way of thinking and working that is based on evidence and logic. The scientific method is used in many different fields, including biology, chemistry, physics, and earth science. It is a process that is constantly being refined and improved, and it is one of the most important tools that scientists have.

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wave length or whole resonant period and this cannot be true as is explained in the theory above.

Lenard assumed the existence of complicated conditions of motion of the electron within the body and that the initial velocity is not derived from the light energy but from the energy of those movements already existing before illumination takes place. In this case the resonant vibration only acts as a liberator, the electrons being liberated when it reaches the major axis of its orbit and well out to or beyond the limit of attraction. This theory is very good but again we are confronted by the question, "Is it possible that all wave-lengths of light will produce resonant vibration", yet it is a well established fact that all wave-lengths do produce photo-electric effects of varying intensities.

Einstein in an endeavor to connect some of Plank's results from radiation of black bodies or " h " (Plank's universal constant of action) with photo-electricity brought out this theory. The Kinetic energy of the liberated electrons is $\frac{1}{2}MV^2$. The equation for the liberation of photo-electrons is $h\nu - P = \frac{1}{2}MV^2$, where " h " is Plank's constant and is equal to $h = 6.555 \times 10^{-27}$ ergs/sec., " ν " the frequency and " P " the work necessary to liberate the electron. This liberating energy is the product of the potential difference V and the charge " e ". At first this theory seemed to be without foundation, but was later proved by Millikan to be correct, that is he proved it to his own satisfaction. According to this we

may write the equation for the liberation of electrons by light
 thus: $h\nu - P = \frac{1}{2} MV^2 = \underline{Y_e}$. A slight modification of Lenard's
 theory enables us to see that this equation holds for that theory.
 Let $h\nu$ = energy of the electron within the atom; P = the energy
 necessary to liberate the electron; $\frac{1}{2}MV^2$ the energy of the liber-
 ated electron, and $\underline{Y_e}$ the product of the difference of potentials
 and the charge to give the electron the Kinetic energy of $\frac{1}{2} MV^2$.
 Thus modified Einstein's equation will read: $\underline{Y_e} = \frac{1}{2}MV^2 = h\nu = P$;
 "P" in this case being derived from the light that has acted only
 in the role of liberator. The energy of the free electron being
 that derived from within the atom. Arriving at this same con-
 clusion from two independent sources we are justified in believing
 that the theory is correct.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part outlines the specific procedures for recording transactions, including the use of standardized forms and the requirement for double-checking entries to prevent errors.

3. The third part addresses the role of the accounting department in monitoring and reporting on the organization's financial health. It highlights the need for regular audits and the preparation of detailed financial statements.

4. The fourth part discusses the importance of maintaining up-to-date information on the organization's assets and liabilities. It stresses that this is essential for making informed decisions about resource allocation and risk management.

5. The fifth part concludes by reiterating the commitment to transparency and accountability, and encourages all staff members to adhere to the established procedures and standards.

Bohr's Theory of the Atom

Bohr had two very definite fundamental hypotheses, - the first one is that for each atom or atomic system there exists a number of definite states of motion, called "stationary states" in which the atom, or atomic system, can exist without radiating energy. A finite change in the energy content of the atom can take place only in a process in which the atom passes completely from one stationary state to another; the second hypothesis states that if such a change takes place with the emission or absorption of electro-magnetic light waves, these waves will have a definite frequency, the magnitude of which is determined by the change in the energy content of the atom. If we denote the change in energy by " E " and the frequency by " ν " we may write $E = h\nu$; $\nu = \frac{E}{h}$ where " h " is the Plank constant. In consequence of the second hypothesis the emission as well as the absorption of energy by the atom always takes place in quanta. $h = 6.555 \times 10^{-27}$ ergs/sec. Another statement of E is $E = E_1 - E_2$, and is usually written ΔE .

If for the hydrogen atom we consider that the orbit of the electron is circular with the nucleus as the centre, and if we consider the mass of the nucleus infinite compared with that of the electron, the centrifugal force is $F = M\omega^2 r$, (F = centrifugal force, M = mass, ω = angular velocity) and the force of

attraction between the electron and the nucleus is $\frac{e^2}{r^2}$, because the charge on the nucleus is positive (+) and that of the electron is negative (-) and they are equal, and "r" is the distance between the electron and the nucleus.

Since the force out and the force in must be equal for a system in equilibrium -

$$M\omega^2 r = \frac{e^2}{r^2} \text{ or } M\omega^2 r^3 = e^2 \quad (I)$$

$$\text{K.E.} = \frac{1}{2}MV^2; \quad F = MV^2; \quad \text{by definition (from classical theory)}$$

$$V = \omega r \quad (\omega = \text{omega})$$

$$\therefore \text{K.E.} = \frac{1}{2}M\omega^2 r^2 \text{ and } F = M\omega^2 r$$

The kinetic energy of the atom = $\frac{1}{2}M\omega^2 r^2$. P.E. is the potential energy or the work necessary to bring the electron from infinity to the nucleus. This P.E. due to -e at a distance r from the nucleus is $\frac{-e^2}{r}$ the work done being negative because the charge on the electron is negative. The total energy of the atom "W", or the work done, is K.E. + P.E.

$$\therefore W = \text{KE} + \text{PE} = \frac{1}{2}M\omega^2 r^2 - \frac{e^2}{r} \text{ but } M\omega^2 r = \frac{e^2}{r^2}$$

$$\text{then } W = \frac{e^2}{2r} - \frac{e^2}{r} = \frac{-e^2}{2r} \quad (II)$$

If the orbit changes from radius "1" to radius "2" the change in energy of the atom is $\frac{e^2}{2r_2} - \frac{e^2}{2r_1}$

but according to the quantum theory -

$$\frac{e^2}{2r_2} - \frac{e^2}{2r_1} = h\nu_t; \quad (III)$$

where ν_t = the frequency of the emitted energy.

The quantum specification of Sommerfeld is a foundation for this, which is $\int P dq = nh$

q = any defining ordinate of the system

P = corresponding momentum

n = a whole number

For hydrogen atoms the orbit being circular, we may express the motion in polar co-ordinates: ϕ, r .

r is constant; $\underline{W} = \frac{d\phi}{dt}$; let $q = \phi$; $P = M\underline{W}r^2$

$$\int_0^{2\pi} M\underline{W}r^2 d\phi = nh$$

$$2\pi M\underline{W}r^2 = nh$$

$$M\underline{W}r^2 = \frac{nh}{2\pi}$$

The whole angular momentum $M\underline{W}r^2$ is an integral number of times $\frac{h}{2\pi}$

$$\text{Then from (I)} \quad M\underline{W}^2 r^3 = e^2 \quad (1.)$$

$$r = \frac{e^2}{M\underline{W}^2 r^2}$$

substituting values of r^2 and $\underline{W}^2$ in terms of equation (1.)

$$\text{and } r = \frac{n^2 h^2}{4\pi e^2 M} \quad (IV)$$

Then from equation (II) substituting values of r ; equation (IV)

$$\text{will read - } \frac{2\pi^2 e^4 M}{n^2 h^2}$$

now from (III) if N_1 and N_2 are orbits -

$$h\nu_t = \frac{2\pi^2 e^4 M}{n_1^2 h^2} - \frac{2\pi^2 e^4 M}{n_2^2 h^2}$$

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$$\text{or } v_t = \frac{2\pi^2 e^4 M}{h^3} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \dots \right)$$

$$v = \frac{v_t}{c} = \frac{2\pi^2 e^4 M}{ch^3} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \dots \right)$$

$$v = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$R = 109732; \quad v = \text{wave number}$$

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Sources of Light

During the very early experiments in photo-electricity the spark was the only artificial source of light. This source however, gave a very limited supply of light of the short wave lengths and as the experiments became more intensive more adequate light sources were sought. The spark naturally led to the arc as a source and it was found that the arc gave a much richer supply of light in the short wave lengths. The one great difficulty encountered by using the arc is the extremely high temperature present resulting in uncertainty. This may be overcome by placing a shield over the arc and insulating and ventilating it so that an air current is created, the direction of the air current being from the plate toward the arc and not vice-versa.

Another exceptionally good source of light is the quartz-mercury-arc. This is a simple mercury arc enclosed in a quartz tube. The quartz tube is essential as most other substances such as glass would be opaque to wave lengths shorter than $3500\text{\AA}$. If this tube is properly constructed and the radiation of heat is adequate little effect of temperature will be realized. This source is

rich in short wave lengths and almost free from the longer wave lengths. In using the quartz tube the thickness is a very important factor. Fused quartz 6 mm thick will transmit light of 1250 μ but the thicker the quartz the more opaque it becomes to short wave lengths.

For our purpose the arc is used. It is shielded and properly ventilated that the air currents are from the plate to the arc and thus the temperature effect is reduced to a minimum. Then we used the arc as it is more flexible and variations of light can be easily obtained if it should be needed at any time. Therefore for our purpose the carbon arc, using $3/8$ inch solid carbon rods, seem to be the most practical.

Photo-electric Fatigue

The decreasing of the photo-electric effect of metal plates and other substances after being exposed to light for a period of time is called "PHOTO-ELECTRIC FATIGUE". This phenomenon has been known from the very beginning by experimenters. Hertz, Hallwachs, Hoor, Stoletow, Elster and Geitel all observed that metal plates aged rapidly when exposed to light. Hallwachs found that after ageing the plates, almost no photo-electric effect was realized from a plate that was photo-electric before exposure to light. What is the cause of photo-electric fatigue?

1. Is there a chemical change? (Oxidation)
2. Does fatigue depend upon the size of the container?
3. Is there a roughening of the surface or a physical change?
4. Is there an electrical change, the formation of a double layer?
5. Is there a change in the surface due to a film of gas, or in the occluded gas in the metal?

One thing must be kept in mind, however, and that is the phenomenon is not always the same, each substance might and probably does vary according to its composition.

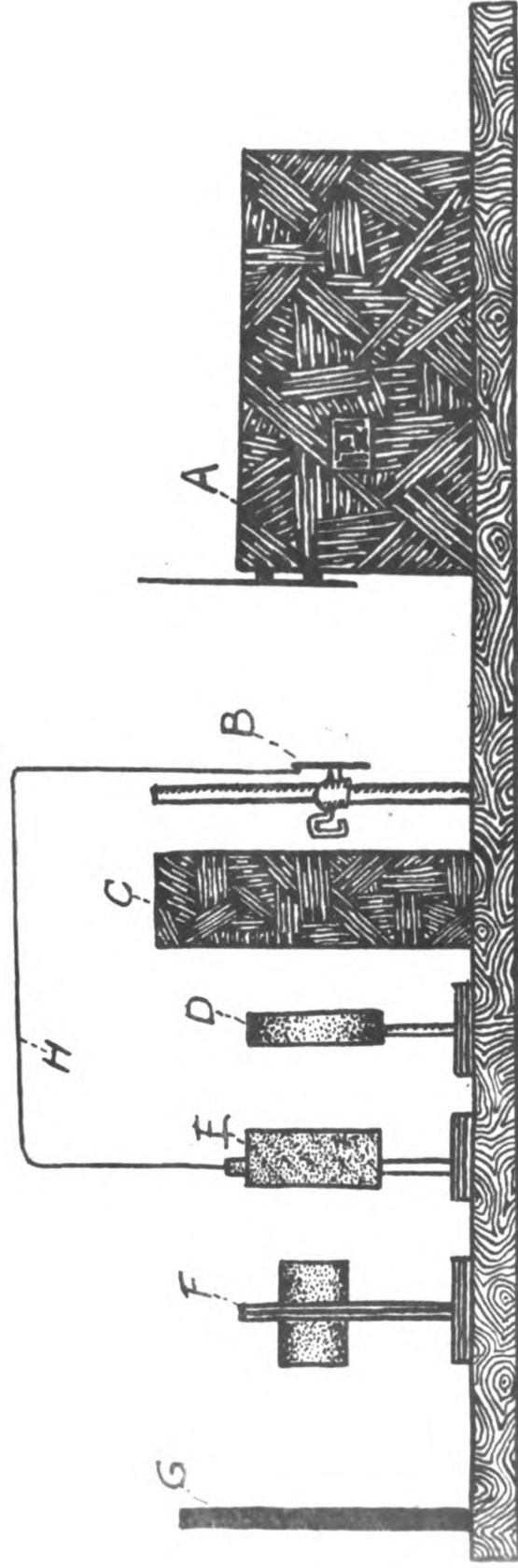
It is not likely that there is a chemical change because Kreuzler has proved that a zinc plate that had been polished and kept in the dark for hours showed an activity equal to a freshly polished plate. Then the same plate showed fatigue after exposure to light. Another proof is that the same plate that showed fatigue became active after being kept in a dark place for a few hours. This last would also prove that fatigue is not due to roughening, as nothing was done to the plate to change its physical condition back to the starting point. H. S. Allen says, - "light is not the primary cause of fatigue, though it may play a secondary part in accelerating or retarding fatigue".

Does fatigue depend on the size of the containing vessel? I will not discuss this question because it has no bearing upon my work as I used no containing vessel. I will, however, quote the conclusion of H. S. Allen, - "The rate at which the fatigue proceeds diminishes with the size of the containing vessel".

Does photo-electric fatigue depend on the electrical condition of the plate? Kreuzler, Hallwachs, V. Schewidler and Sodzewicz all tried this experiment and found that the double layer effect is not the primary cause but may contribute in some degree, and that no connection could be made between that contact potential and fatigue. Having eliminated the first four possible causes so far as my work is concerned, it seems evident that the

fifth is the cause; at any rate most authorities agree that to the best of their knowledge, it is the cause. It is a known fact that a powerful source of ultra-violet light will produce ozone. This was found by H. S. Hower in the early ninties. H. S. Allen makes the following statement, - "A very powerful source of ultra-violet light may cause an increased fatigue in consequence of the production of ozone, which is one factor in bringing about a diminution of the photo-electric current". Winchester and Millikan make the following statement, with regards to the absence of fatigue in a high vaccum, - "It further shows that the phenomenon of photo-electric fatigue as ordinarily observed is one which has its seat in the gaseous layer surrounding the metal rather than in the metal itself". With these three authorities arriving at the same conclusion independently, we can, with confidence, assume that photo-electric fatigue is due to the formation of a gaseous layer on the metal. In my observations I would say that photo-electric fatigue has been realized. In one case where I was testing redwood-carbon of grain number 40, (that is, it had passed through a number 40 screen upon a number 60 screen), the time to pass over 10 scale divisions was 56.80 seconds, and after five minutes exposure, not steady exposure but intermittant exposure, the time increased to one minute nine seconds average. Another case was with northern-pine carbon. The average time of discharge of 10 scale divisions was 14 seconds and after 2 minutes exposure to light the time increased, for the same discharge, to 27.50

seconds. Another case was a "Golden Brown Dye" manufactured by the Monroe Drug Company. The average of 6 readings for a 10 scale division discharge was 32.30 seconds, and the average of the last six readings 44.75 seconds. No attempt was made to determine whether or not they would revive, but from observation when redwood-carbon was tried again I noted some evidence of recovery from fatigue.



Apparatus

A- Arc light shield; B- Plate holder; C- Shield and light;
D- Condensing lens; E- Electroscop; F- Projection lens;
G- Screen; H- Wire.

The Photo-electric Effect
of
Finely Divided Carbon
and
Certain Other Substances

The set-up to measure the photo-electric effect must consist of a source of ultra-violet light, and electrometer or an electroscope and a holder for the plate. If an electroscope is used, a lens system including a source of light (other than the ultra-violet), and a screen upon which to project the image of the gold leaf of the electroscope must be used. The set-up used is illustrated by a photograph opposit this page.

The size of the plate for the various substances to be tested is not important as long as it is small enough to have the light fall upon it at near normal incidence. The size used was 5 x 6 cm. It is important, however, that the plate be not photo-electric. Several plates of different substances were tried and discarded, but common black stovepipe iron was found to be non-photo-electric. This was true, however, when the oxide due to its manufacturing process was still on the plate. When this oxide was removed and the plate polished, it became photo-electric.

It is important that the plate be very clean; all greases and other foreign substances must be removed. The first cleaning

process was to rinse the plate in hot water, then wash in hot KOH, rinse thoroughly in hot water, and then carefully dry. This process was not successful because the plate became photo-electric. This was due to one of two reasons, either a film of KOH was still on the plate, or the oxide had been reduced and the ultra-violet light passed thru it to the metal. To test the first supposition the plate was rinsed in alcohol after it had been rinsed in water the second time. This did not solve the problem, but by careful examination it was found that the oxide had been reduced. Then alcohol alone was used to clean the plate and the same condition was found. It was thought that perhaps some foreign substance in the alcohol was the cause, so redistilled alcohol was used with no change in results. Finally hot water and Jap Rose soap was used and it was found that this cleaned the plate and did not change it's photo-electric properties.

The fact that alcohol could not be used, presented another problem. It had been planned to use alcohol as a solvent for some of the dyes that were to be tested. It is necessary when a plate is prepared to have an evenly distributed film of the substance on the plate, but due to the fact that alcohol affected the plate it could not be used. After trying several solvents, (acetone, alcohol, redistilled alcohol, hot alcohol, hot acetone, water and hot water) to find one that would not affect the plate but still give an evenly distributed film,

it was found that the plate could be prepared by dusting the substance onto it. After the plate had been cleaned, every precaution was taken to keep it clean. The plate was tested before the substances were dusted on and if found to be photo-electric it was cleaned. If it again showed a trace, the plate was discarded.

The ultra-violet light was obtained from a carbon arc, using $3/8$ inch solid carbon rods. The length of the arc is an important factor and this was controlled by measuring the voltage across the arc. It was found that this method kept the distance more constant than was possible by measuring. The resistance was adjusted to give a current of 27 amperes and the arc adjusted so that the potential across it was 40 volts. The source of current was not constant, therefore averages were taken to reduce any errors.

The readings were taken for 10 scale divisions. They are as follows: scale reading when ultra-violet light was turned on, time for gold-leaf to pass over 10 scale divisions, scale division when ultra-violet was turned off, voltage across arc during this time. There was no particular reason for choosing just these values, but they were accurately kept.

There is no set standard used, so zinc was selected. The reason for this choice is that zinc has a very marked photo-electric effect and the plate could be polished very readily. There are two reasons for using a standard. First, the standard

plate can be used as a comparative value for all other substances. Second, the polished plate can be preserved and used as a check from time to time to insure accurate readings. A question might arise here as to why we polish the plate. First, to remove all oxides so that we have clean metal. Second, the contour of a rough plate contains hills and valleys, so to speak, and we polish the plate to make the surface as nearly plane as possible.

Before turning the ultra-violet light upon the plate, the system, (plate, connecting wire (H) and electroscope (E), figure 3) was charged with a negative charge. Then the ultra-violet light was turned on. If the substance under test was photo-electric, the electroscope immediately began to discharge with a definite rate. This operation was repeated several times and readings taken for 10 scale divisions and the average taken. The average for the standard plate was found to be 5.007 seconds for a 10 division discharge. This average was obtained for one hundred readings with a potential across the arc of 41.28 volts. This then will be considered as the standard value and all other values will be compared with it.

An error that may creep in without being noticed is the thermal effect, by this we mean the effect of temperature upon various substances. If the system described above is charged positively, substances sometimes show apparent photo-electric effect. To avoid this error a test was made on each substance. The test was a simple one. The system was charged positively

and the ultra-violet turned on and the time noted. In every case no photo-electric effect was noticed for a 60 second exposure.

The Photo-electric Effect of Finely Divided Carbons

There is no chemical difference in the different carbons found in table I, but we list them according to their source, keeping in mind that they differ in origin and degrees of hardness. Thus a carbon listed as "redwood carbon" is carbon obtained by partially burning redwood and grinding the residue in an agate mortar.

The question may arise, "Is the carbon finely divided?" Fig. 4 is a photo-micrograph of carbon that has been ground in an agate mortar. Fig. 5 is a photo-micrograph of carbon that has passed through a 100 mesh screen. The photo-micrograph Fig. 6 is carbon that was deposited upon the plate by holding it at a distance of eight inches over the flame of burning parafine.

The carbons were dusted upon the plates and all excessive particles were removed by jarring the plate. In some cases it was deemed advisable to brush or rub the particles on the plate. Whenever this was done, rice paper or absorbant cotton was used.

It is evident that the harder the carbons the more active the photo-electric effect, as is shown in table I. Cypress, poplar, redwood, southern pine and northern pine are of the soft grade of

carbon. They have a flaky and needle-like structure. Table I. will show that they are not as active as parafine carbon, arc carbon, chestnut, red-oak, black-walnut and gum-wood which are hard and have a distinctive granular structure.

It was further noted that the softer grades of carbons would stick to plate much better, thus more particles would be deposited upon the plate per square centimeter. Naturally a greater photo-electric effect was expected, however, the reverse proved to be true. Therefore, the hard carbons are more active than the soft carbons.

The size or the fineness of the carbons seem to modify the photo-electric effect. Redwood carbon, A - table I, is carbon ground in a porcelain mortar. It was coarse and flaky. Note, it is not very active, in fact it is so slow that one might almost discard it. Note further from table I. that the finer the carbon the more active the photo-electric effect. Redwood carbon, 100 fine, is twice as active as redwood carbon 40 fine. Parafine carbon after it had been brushed with rice paper, was more active. Therefore, from the data obtained, we have sufficient proof that the fineness of the carbon does have an effect upon the photo-electric effect.

The age of the carbon did not seem to have any effect upon the photo-electric effect. Redwood carbon, 3 - table I, is carbon one week old, its activity is 0.194. Redwood carbon 100 is fresh carbon, its activity is 0.168. The difference in activity is too small to prove any change in the photo-electric effect due to the age of the carbon.

Table I

Name	Note	Scale Division	Time of Discharge	Voltage Across Arc	Comparison of Standard or $\frac{5.067}{1}$
Parafine carbon	2	10	9.240	41.100	0.542
" "	1	10	8.300	41.700	0.603
Parafine	4	10	-----	40.000	-----
Camphor gum	1	10	26.560	42.300	0.189
Poplar carbon	5	10	26.541	41.200	0.189
Southern pine	5	10	23.770	41.400	0.210
Bone black	-	10	43.200	41.100	0.119
Northern pine	5	10	23.140	43.200	0.216
Redwood	A	10	70.870	41.450	0.071
Redwood 100	7	10	29.734	40.000	0.168
Redwood 80	7	10	44.720	40.000	0.112
Redwood 60	7	10	66.742	40.000	0.075
Redwood 40	7	10	64.940	40.000	0.077
Redwood	3	10	30.900	40.000	0.194
Cypress	5	10	13.710	42.200	0.453
Arc carbon	6	10	19.290	41.000	0.261
Chestnut	5	10	17.726	40.636	0.283
Red-oak	5	10	16.557	42.315	0.302
Gum-wood	5	10	19.210	42.421	0.260
Black-walnut	5	10	19.000	40.770	0.264

Notes:

1. Brushed on plate with rice paper or absorbant cotton.
2. Held over the flame at a distance of 8 inches.
3. Carbon one week old.
4. Plate dipped in hot parafine and cooled.
5. Carbon ground in agate mortar and passed through 100 mesh screen.
6. Carbon collected at base of the arc and brushed on the plate with rice paper.
7. 40 carbon means passed through number 40 screen upon a number 60 screen.
60 carbon means passed through number 60 screen upon a number 80 screen.
80 carbon means passed through number 80 screen upon a number 100 screen.
100 carbon means passed through number 100 screen upon pan below.

1. The first part of the document is a list of names and their corresponding addresses.

Name	Address	City	State	Zip
John Doe	123 Main St	New York	NY	10001
Jane Smith	456 Elm St	Los Angeles	CA	90001
Bob Johnson	789 Oak St	Chicago	IL	60601
Alice Brown	101 Pine St	Houston	TX	77001
David White	202 Cedar St	Phoenix	AZ	85001
Emily Green	303 Birch St	San Francisco	CA	94101
Michael Black	404 Maple St	Dallas	TX	75201

Page 10

The second part of the document is a list of names and their corresponding addresses.

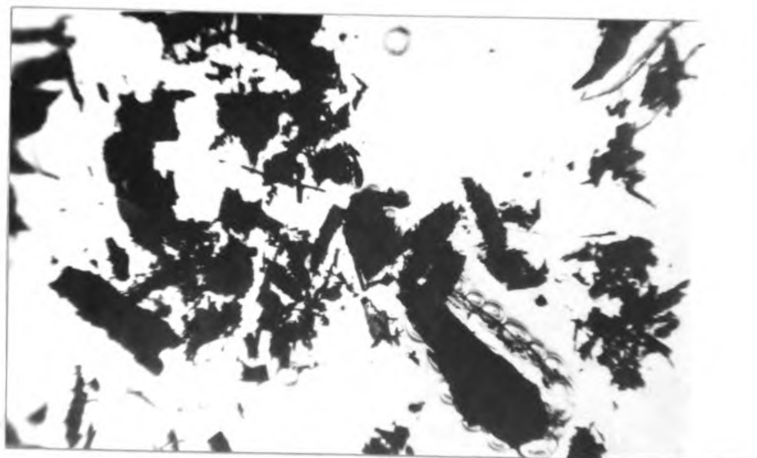


Fig. IV



Fig. V.



Fig. VI.

A Photo-electric Study
of
Certain Dyes

Are dyes photo-electric and does their position in the spectrum indicate that they are photo-electric? In answer to this, reference will be made to certain dyes that were tried. A scarlet dye (Putnam) was tried and found to be photo-electric, but not very active. (Table II) Near the scarlet in the spectrum is the turkey red. Turkey red is darker than scarlet but is much slower, having a discharge time of 18.685 seconds. (Table II) The next in position is yellow (Putnam). This is very slow, having a discharge time (10 divisions) of 43.68 seconds; it being only 0.115 as active as the standard. Bright green (Putnam) compares favorably with the scarlet. (Table II) The olive green (Putnam) is darker green and is slower. (Table II) Navy blue (Putnam) is slower than the standard, having a discharge time of 13.389 seconds. Dissolving the navy blue in alcohol, it was found that the photo-electric effect (Table II) is very active. The inaccuracy of this test is the effect of the alcohol upon the plate as explained on page 22. Indigo (Dow) is very active (Table II) being 0.782 as active as the standard. Purple violet (Putnam) is somewhat slower than indigo, but compares favorably with the standard (Table II).

Table II

Name	Scale Division	Time and Discharge	Voltage Across Arc	Comparison of Standard $\frac{5.007}{1}$
Scarlet (Putnam)	10	13.415	40.615	0.373
Turkey Red (Putnam)	10	18.685	40.285	0.268
Yellow (Putnam)	10	43.680	40.000	0.115
Bright Green (Putnam)	10	14.914	43.500	0.336
Olive Green (Putnam)	10	29.557	41.714	0.171
Navy Blue (Putnam)	10	13.389	41.536	0.374
Navy Blue (Putnam - dissolved in alcohol)	10	8.787	41.333	0.569
Indigo (Dow)	10	6.400	43.800	0.782
Purple Violet (Putnam)	10	14.914	43.500	0.725
Scarlet (Putnam)	10	5.480	41.200	0.914 - ?
Indigo (Dow - dissolved in alcohol)	10	3.720	40.000	1.346

The first part of the question is answered - dyes are photo-electric. The second part seems doubtful, as the data obtained for dyes in the red end of the spectrum, do not seem to be constant, but from data of the dyes in the blue end of the spectrum, it seems that as the dye approaches the shorter wave-lengths the photo-electric effect increases.

The Photo-electric Effect of Miscellaneous Substances

Metals have been tested many times and little will be said here except to call attention to a few conditions that were tested. Tinfoil was tested and found to be photo-electric. (Table III) Then the same plate was moistened with distilled water and the photo-electric became more active. A copper plate was tested, the oxide was removed and the plate polished, and as expected it was found to be photo-electric. This test was used as a comparison. A thin film of copper was electroplated upon the polished surface and it was found that the photo-electric activity had been greatly reduced. The plate was then polished and it was found to be more active. However, test (c) did not prove to be as active as test (a) which was due to the fact that the copper plate was softer and could not be polished as highly

as the original plate. (Table III - conditions (a), (b) and (c)) A brass plate was then tried and found to be very active. (Table III) The best results were obtained from a tin plate. The plate was cleaned and tested and it was found to be very close to the standard plate, having a discharge time of 5.106 seconds.

A plate was made of chlorophyll. A solution of chlorophyll was obtained by dissolving a catulpa leaf in hot alcohol. This solution was then pored upon a plate in such a manner that a uniform film was produced; then the alcohol was allowed to evaporate, leaving a film of chlorophyll. The plate was not very good as it was almost impossible to get a very thick film of chlorophyll on it. Table IV shows that it is not active. Then catupla, maple and elm leaves were tried and it was found that they also were not active. Note Table IV, that the time for 1 scale division discharge was 42 seconds, for the elm leaf. From the data in this table it is believed that leaves are not photo-electric.

A plate was prepared by heating iodine and allowing the vapor to condense upon the cold plate. From this test it was found that iodine was photo-electric but not very active. (Table IV)

A plate was prepared by molding a plate of sulphur 5 x 6 cm. and tested. It was found to be non-photo-electric. (Table IV)

The standard plate was again tried but this time a quartz window was placed in the light stream and from Table V will be seen that the photo-electric effect was changed but very little. A thin photographic film was used as a filter and from Table V(a), it will be seen that the photo-electric effect was greatly reduced. Then another film, of double the thickness of the first, was tried and the effect was reduced still more. Then a film of three times the thickness of the first was tried and the effect was reduced a great deal more. These films were prepared by exposing photographic films 5, 10 and 15 seconds.

The effect of ray filters upon the photo-electric effect was next studied. A No. 6 Eastman ray filter (light yellow), No. 9 Eastman ray filter (dark blue), No. 1 Eastman ray filter (dark red) were tested. No effect was observed with No. 6 or No. 9, but with the No. 1 a reading of 105.3 seconds for 1 scale division was obtained, which was opposite to what may have been expected. More light passed through the No. 6 filter and light of shorter wave-lengths passed through the No. 9 filter. This test was repeated within one-half an hour and the readings checked within 0.6 seconds.

Therefore, carbons are photo-electric; the photo-electric effect depending upon the fineness and hardness of the carbon particles. Dyes are photo-electric and the effect increases as we go from the red toward the violet dyes. Certain

metals are more photo-electric than other substances, the photo-electric activity of any one of them varying with the degree of polish. Leaves are photo-electric. Sulphur is not photo-electric. Iodine is slightly photo-electric, but not very active.

In general, most substances are at least slightly photo-electric. The substances that have been proven to be non-photo-electric might possibly be slightly photo-electric if tested under different conditions.

Table III

Name	Scales Division	Time and Discharge	Voltage Across Arc	Comparison of Standard <u>5.007</u> 1
Tinfoil	10	31.440	40.000	0.159
Tinfoil & H ₂ O	10	30.940	40.000	0.162
Copper - polished (a) (not electroplate)	10	7.300	41.060	0.686
Copper - rough (b) (electroplate)	10	22.300	40.000	0.225
Copper - polished (c) (electroplate)	10	9.220	41.200	0.543
Brass	10	6.960	40.130	0.720
Tin Plate	10	5.106	40.130	0.981

1. The first part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

2. The second part is a list of the names of the persons who have been appointed to the various offices of the city.

3. The third part is a list of the names of the persons who have been appointed to the various offices of the city.

4. The fourth part is a list of the names of the persons who have been appointed to the various offices of the city.

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9. The ninth part is a list of the names of the persons who have been appointed to the various offices of the city.

10. The tenth part is a list of the names of the persons who have been appointed to the various offices of the city.

Table IV

Name	Scales Division	Time and Discharge	Voltage Across Arc	Comparison of Standard <u>5.007</u> 1
Iodine	10	36.787	40.000	0.137
Sulphur	10	-----	40.000	-----
Chlorophyll	10	78.181	42.272	0.064
Elm leaf	1	29.500	42.000	0.017
Catulpa leaf	1	33.200	40.000	0.015
Maple leaf	1	28.000	41.500	0.018

Table V

Name	Scales Division	Time and Discharge	Voltage Across Arc	Comparison of Standard <u>5.007</u> 1
Standard	10	5.007	41.280	1.000
Standard - with quartz	10	6.000	40.000	0.835
Standard (a)	1	64.100	40.000	0.008
Standard (b)	1	70.600	40.000	0.067
Standard (c)	1	81.400	40.000	0.006

Note:

- (a) - A photographic film exposed 5 seconds.
- (b) - A photographic film exposed 10 seconds.
- (c) - A photographic film exposed 15 seconds.

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STRUCTURE OF THE ATOM

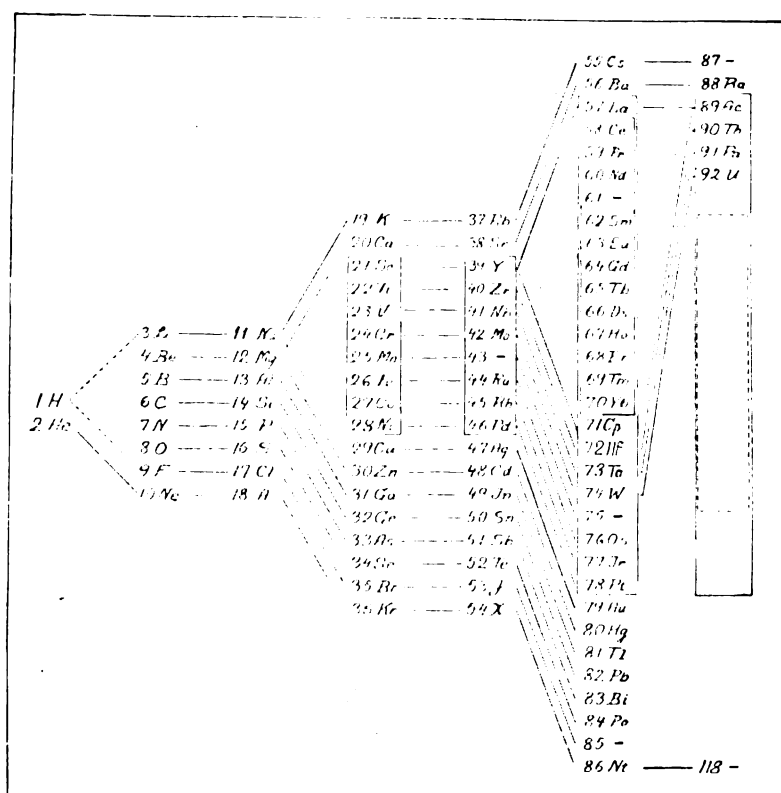


FIG. 34. The periodic system of the elements. The elements where an inner group of orbits is in a stage of reconstruction are framed. The oblique lines connect elements which in physical and chemical respects have similar properties.

THE PERIODIC OR NATURAL SYSTEM OF THE ELEMENTS

O	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	1 Hydrogen H 1.008							
2 Helium He 4.00	3 Lithium Li 6.94	4 Beryllium Be 9.1	5 Boron B 11.0	6 Carbon C 12.0	7 Nitrogen N 14.0	8 Oxygen O 16	9 Fluorine F 19.0	
10 Neon Ne 20.2	11 Sodium Na 23.0	12 Magnesium Mg 24.3	13 Aluminium Al 27.1	14 Silicon Si 28.3	15 Phosphorus P 31.0	16 Sulphur S 32.1	17 Chlorine Cl 35.5	
18 Argon Ar 39.9	19 Potassium K 39.1	20 Calcium Ca 40.1	21 Scandium Sc 44.1	22 Titanium Ti 48.1	23 Vanadium V 51.0	24 Chromium Cr 52.0	25 Manganese Mn 54.9	26 Iron Fe 55.8 27 Cobalt Co 59.0 28 Nickel Ni 58.7
	29 Copper Cu 63.6	30 Zinc Zn 65.4	31 Gallium Ga 69.9	32 Germanium Ge 72.5	33 Arsenic As 75.0	34 Selenium Se 79.2	35 Bromine Br 79.9	
36 Krypton Kr 83.6	37 Rubidium Rb 85.4	38 Strontium Sr 87.6	39 Yttrium Y 88.9	40 Zirconium Zr 90.6	41 Niobium Nb 93.3	42 Molybdenum Mo 96.0	43 —	44 Ruthenium Ru 101.1 45 Rhodium Rh 102.9 46 Palladium Pd 106.4 47 Silver Ag 107.9
	47 Silver Ag 107.9	48 Cadmium Cd 112.4	49 Indium In 114.8	50 Tin Sn 118.7	51 Antimony Sb 120.2	52 Tellurium Te 127.5	53 Iodine I 126.9	
54 Xenon Xe 131.3	55 Caesium Cs 132.9	56 Barium Ba 137.3	57 Lanthanum La 139.0	58 Cerium Ce 140.2	59 Praseodymium Pr 140.6	60 Neodymium Nd 144.3	61 —	62 Samarium Sm 150.4 63 Europium Eu 152.0 64 Gadolinium Gd 157.3 65 Terbium Tb 158.9 66 Dysprosium Dy 162.5 67 Holmium Ho 164.9 68 Erbium Er 167.3 69 Thulium Tm 168.9 70 Ytterbium Yb 173.0 71 Lutetium Lu 175.0
			72 Hafnium Hf 179	73 Tantalum Ta 181.5	74 Tungsten W 184.0	75 —	76 Osmium Os 190.0 77 Iridium Ir 192.2 78 Platinum Pt 195.1 79 Gold Au 197.0	
80 Mercury Hg 200.6	81 Thallium Tl 204.0	82 Lead Pb 207.2	83 Bismuth Bi 209.0	84 Polonium Po 210.0	85 —			
86 Radium Ra 226.0	87 Actinium Ac 227.0	88 Thorium Th 232.0	89 Protactinium Pa 231.0	90 Uranium U 238.0	91 —			

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