health-giving qualities of the tree, as possibly having suggested to them the name arbor vitae, tree of life. When the speaker had sat down, Dr. Leidy, in his quiet manner, said that such and such a Latin physiology published some time in 1600, refers to a small filament at the base of the brain, which from its tree-like form was called arbor vitae, the tree of life, and that he had always assumed that the great similarity of this filament to the form of the arbor vitae had led to the tree's name. Thus it was that Leidy from his broad and profound knowledge would bring out some such point which the writer of an elaborate paper had overlooked. In this case the writer being *only* a botanist was not aware of the filament at the base of the brain.

R. C. CANBY

EXHIBITION OF THE ROYAL PHOTOGRAPHIC SOCIETY

THE Royal Photographic Society of Great Britain are holding their sixty-ninth annual exhibition in September and October of this year. This is the most representative exhibition of photographic work in the world, and the section sent by American scientific men heretofore has sufficiently demonstrated the place held by this country in applied photography. It is very desirable that American scientific photography should be equally well represented in 1924, and, in order to enable this to be done with as little difficulty as possible, I have arranged to collect and forward American work intended for the scientific section.

This work should consist of prints showing the use of photography for scientific purposes and its application to spectroscopy, astronomy, radiography, biology, etc. Photographs should reach me not later than Saturday, June 14. They should be mounted but not framed. There are no fees.

I should be glad if any worker who is able to send photographs will communicate with me as soon as possible so that I may arrange for the receiving and entry of the exhibit.

A. J. NEWTON

EASTMAN KODAK COMPANY,
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SCIENTIFIC BOOKS

A Comprehensive Treatise on Inorganic and Theoretical Chemistry. Vol. IV.—Ra and Ac Families, Be, Mg, Zn, Cd, Hg. By J. W. MELLOR. 1074 pages. Longmans, Green and Co., London, 1923. Price, $20.00.

VOLUME IV of the "Comprehensive Treatise" represents an important addition to the volumes already published. (For review of Vols. I–III, see SCIENCE, Vol. 58, No. 1500, (1923)). This is particularly true because of the fact that the treatment of the radioactive elements is expanded to include a discussion of the modern theories of atomic structure and valence, which were omitted entirely from the chapters on valence and similar subjects in Vol. I. The first chapter deals with the structure of matter, treated broadly and historically; the second treats the radioactive elements; and the third is entitled "The Architecture of the Atom." A very considerable amount of data is given, and the references are full and apparently up to date. The author makes no attempt to correlate conflicting theories, a task which is, after all, better left to monographs on the subject. The student will find in these chapters much to interest and stimulate him.

The remaining chapters are devoted to an exhaustive study of the elements listed on the title page. Beryllium and magnesium are treated separately; zinc and cadmium together; mercury separately. The method of treatment is similar to that employed in the earlier volumes. Each element is taken from the most remote reference to it in literature, and is brought down to quite recent dates, with abbreviated statements of apparently almost all the work that may have been done, and with very full references. In the opinion of the reviewer the book would have been improved if a somewhat more critical attitude had been taken, more space being given to apparently reliable data, and less to some of the older data. Nevertheless, these abbreviated statements must arouse the interest and curiosity of the student perhaps even *because* of their failure to give full information, and the frequent absence of logical sequence. Thus, " . . . , the electric sparking of cadmium under liquid argon produces a voluminous olive-green powder, which . . . is thought to be a nitride. According to O. Sackur, the catalytic activity of the following metals on the combustion of hydrogen decreases in order Ag, Pt, Cu, Pb, Zn, Ni, Sn, Fe, Cr." Altogether, Volume IV maintains very satisfactorily the standard set by the earlier volumes.

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SPECIAL ARTICLES

A SIMPLE METHOD FOR QUANTITATIVE STUDIES OF IONIZATION PHENOMENA IN GASES

DIRECT measurements of the free paths of electrons in gases and a great deal of other quantitative information regarding the mechanism of ionization may be obtained from a simple type of tube which contains no grid. A straight tungsten *filament, f,* is mounted in the axis of a *cylindrical electrode, c.* Fitting within the ends of the cylinder, but without touching it, are two *end plates, a* and *b* with their planes perpendicular to the axis of the cylinder. The filament, *f,* whose effective length is the same as the distance between the end plates, passes through small holes in the centers of these plates. In most of the experiments the cylinder has been 4 cm. long and 3.2 cm. in diameter.

As an example, let the tube contain mercury vapor at a pressure of 200 bars (0.15 mm). Apply a potential of + 100 volts to *a* and — 10 volts to *c* and *b,* these being measured from the negative end of the filament. Heat the filament to a temperature at which it emits 10 milliamps. of electrons. A positive ion current of 19 m.a. is collected by *c* and this current, which is independent of the negative potential applied to *c,* is a measure of the positive ion current density (0.51 m.a. per cm.^{2}) within the ionized gas.[1] The positive ion sheath covering the inner surface of the cylinder is only 0.9 mm. thick.

Taking into account the relatively large masses of the mercury ions, it can be shown that the average velocities of the ions in the ionized gas must be less than 3×10^5 cm. per sec. and from this it may be calculated that the number of ions per cm.^{3} must exceed $6. \times 10^{11}$ which is about 4,000 times as great as the average density due to the primary electrons from the filament.

The low speed electrons produced by ionization accumulate within the gas until this positive ion space charge is nearly neutralized. The "electron current density" in the gas (in all directions!) is then about 640. m.a. per cm.^{2} which is 180. times greater than the actual current density to the anode *a.* The anode must, therefore, be negative (actually about 6.5 volts) with respect to the gas, *i.e.,* the anode drop is negative. The anode (at + 100 volts!) thus collects as many *positive ions* as a similar electrode (say *b*) at — 50 volts.

The conductivity of the ionized gas, calculated from well-known mobility equations, is so high that a current of 10 m.a. can flow the length of the tube without causing a drop in potential of more than 0.1 volt. The positive ion density, because of the greater primary electron current density, must increase as we pass to points nearer the axis of the cylinder. There must be corresponding differences in the electron densities and these must be brought about by the development of potential differences in these regions whose magnitude can be calculated by the Boltzmann equation.

$$\rho = \rho_0 \, \epsilon^{\frac{Ve}{kT}}$$

[1] Langmuir, SCIENCE, Vol. 58, p. 290 (1923).

where V is the potential difference in volts between two regions in which the electron densities are ρ and ρ_0 respectively. The constant e/k has the value 11,600 degrees per volt; and T is the temperature corresponding to the electron velocities, (15,000° in the case we are considering.)

There is thus within the ionized gas a radial field (about 1 volt difference of potential) which tends to accelerate the positive ions outwards towards *c,* even if *c* is made the anode. This probably explains the fact that the density of the positive ion current collected by *c* is usually 2 to 4 times as great as that to *b* (both electrodes being at negative potentials). In the example considered the ion current to *b* was 1.7 m.a. and we may assume that an equal current of ions was collected by the anode. Calculation from the space charge equations shows that the ion current to the filament can not have exceeded 0.7 m.a. The total ion current to all electrodes was therefore $19 + 2 \times 1.7 + 0.7$ or 23.1 m.a. and these ions were produced by the action of 10 m.a. of primary electrons. Thus 2.31 ions were produced by each electron. Let us denote this ratio by β.

The primary electrons from the filament are strongly accelerated within the sheath around the filament so that when they have traveled a distance equal to the thickness of the sheath (0.4 mm.) they have acquired the full velocity corresponding to the cathode drop (107.5 volts in our example). They then move in strictly radial directions with constant velocity until they collide with atoms or reach the edge of the sheath on the cylinder *c.* In this latter case they penetrate a certain distance within the sheath, but are exposed to a retarding field and if *c* is at a negative potential they are all thrown back out of the sheath, and again move in a radial direction with the original velocity. The electrons thus continue to move back and forth without loss of energy until they collide with atoms or reach the anode because of longitudinal velocities arising from geometrical imperfections in the tube.

If the cylinder *c* is brought to a *positive potential* the retarding field in the sheath is no longer able to prevent primary electrons from reaching *c.* At pressures low enough for an appreciable fraction, γ, of the electrons to reach the collector *c* without having collided with atoms, there is thus an abrupt and accurately measurable change Δ in the current to *c* when the potential is raised from negative values to positive values of one or two volts.[2]

This change, Δ, is due to two factors: (1) the electrons taken up by *c,* and (2) the decrease in the ion current resulting from the removal of these elec-

[2] The potential drop along the filament has been eliminated in many of the experiments by intermittent heating of the filament with a rotating commutator.

trons.[3] It is readily shown that

$$\gamma = \frac{\triangle}{1 - r + \beta_c}$$

where r is the fraction of electrons reaching c which are reflected (about 20 per cent. in the present experiments) and β_c is that part of β which corresponds to positive ion current flowing to c when this electrode is negative ($\beta_c = 1.9$ in our example).

The quantity γ is related to the mean free path λ of the electrons by the equation

$$\gamma = \epsilon^{-c/\lambda}$$

or since the free path is inversely proportional to the pressure p,

$$\gamma = \epsilon^{-cp/\lambda_1}$$

Here c is the radius of the cylinder c and λ_1 is the free path at unit pressure.

The principal source of error lies in the determination of the temperature or density of the gas in the tube. To avoid uncertainty of this kind, tubes are now used with a metallic deposit on the glass wall of the tube itself, used as the collecting cylinder c.

A study of the current-voltage curves obtained with electrodes a and b gives practically full information regarding the number and distribution of velocities of the electrons in the ionized gas. The data obtained in experiments with argon and mercury vapor permit the recognition of 5 distinct classes of electrons in the ionized gas.

Class I. Primary Electrons from Cathode.—These move radially with constant velocity. The mean free path λ, of 50 volt electrons, in argon at 347°K reduced to a pressure of 1 bar, is 69. cm. This free path is practically independent of the energy of the primary electrons between 30 and 225 volts and agrees well with that calculated from the kinetic theory from viscosity measurements (*i.e.*, $4\sqrt{2}$ times the free path of argon *atoms*).

Class II. Electrons Scattered through Small Angles by Elastic Collisions.—About 9 per cent. of the collisions between 100 volt electrons and argon atoms are elastic in the sense that the electrons lose no energy. Over half of these collisions, however, cause the electrons to be deflected through angles of less than 8° and practically none of them result in deflections greater than 15°. The number of collisions resulting in this small angle scattering decreases from about 20 per cent. for 30 volt electrons to 5 per cent. for 225 volt electrons. In mercury vapor no electrons of Class II were observed.

Class III. Electrons which suffer a Definite Energy Loss.—About 24 per cent. of the collisions between 100 volt electrons and argon atoms cause a loss of 13. ± 1 volt energy to the electron and these electrons are deflected through an average angle of about 10°, a few per cent. only suffering deflections as great as 20°. The fraction of collisions giving Class III electrons varies with the velocity of the primary electrons as follows: 0.26 for 50 volt; 0.21 for 150 volts and 0.13 for 225 volt electrons. The energy loss in collisions yielding Class III electrons in *mercury vapor* corresponds to 6.7 volts in agreement with data of Eldridge (*Phys. Rev. 20,* 456, (1922)). They never appear to lose energy corresponding to the ionizing potential (10.4 volts). About 36 per cent. of the collisions of 100 volt electrons with mercury atoms yield Class III electrons and the angular deflections are about the same as with argon.

Class IV. Secondary Electrons of Moderate Velocity.—These electrons move nearly in random directions and have velocities distributed according to Maxwell's law corresponding to a temperature T_4. The current density I_4 (through any imaginary plane from one side to the other) serves as a measure of the number of such electrons. For example, with argon at 44 bars and the anode at 100 volts, with a primary emission of 10 m.a. I_4 was found to be 0.12 m.a. per cm.^{2} and T_4 was 310,000° which corresponds to an average energy for the Class IV electrons of 40 volts. The number of such electrons produced is usually considerably smaller than the number of primaries. It is believed that Class IV electrons are not a direct result of collisions between primary electrons and atoms but are more probably due to photo-electric emission from gas atoms due to ultraviolet radiation from atoms excited by primary electrons. In general, the velocities and number of these electrons decrease as the pressure is raised and increase as the anode voltage is raised.

Class V. Secondary Electrons of Low Velocity.—These electrons move in random directions and with Maxwellian distribution of velocities and have average energies ranging from 0.7 volts at high pressures (1,000 bars) to 10 volts at lower pressures (30 bars) and higher voltages (225 volts). The number of these electrons per unit volume is several thousands of times greater than the number in any other class and it is principally these electrons which neutralize the positive ion-space charge.

The total production of electrons of Classes IV and V must equal the rate of positive ion production measured by β. (β = positive ions per primary electron). The values of β rise from o at the ionizing potential about in proportion to the anode voltage up to about 150 volts and then increase somewhat more slowly. The total ionization β increases only slowly with the pressure. Thus with argon and an anode voltage of 100, β is 1.2 at 20 bars, 1.45 at 50 bars, 1.7 at 100 bars, 1.95 at 300 bars and then de-

[3] This is confirmed by the simultaneous change in positive ion current to b. This changes in the ratio $1 : 1 - \gamma$.

creases at higher pressures probably as a result of recombination. With mercury vapor, the values of β are about 50 per cent. greater.

These results indicate that 60 or even 70 per cent. of the primary electrons lose nearly all of their energy on their first collisions with atoms and the remaining atoms lose energy less than that needed to produce ionization. Since 2 or 3 ions may be formed by each electron it appears that the primary process involved in ionization by 30 to 200 volt electrons is the production of an *excited* atom or ion which takes up nearly the whole energy of the incident electron. Then, by collisions with other atoms, or more probably by radiation, this excited atom causes the ionization of several other atoms.

This mechanism seems essentially different from that postulated in a recent paper by R. H. Fowler (Phil. Mag. *47,* 257 (1924)).

The foregoing results confirm nearly all the conclusions drawn by Eldridge in his study of the ionization of mercury vapor.

Experiments are in progress using hydrogen, helium, nitrogen, neon and carbon monoxide.

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PLURISEGMENTAL INNERVATION OF SKELETAL MUSCLE FIBERS AND IMPLICATIONS CONCERNING FATIGUE

THE traditional picture of the fiber of skeletal muscle represents it as receiving one motor nerve-fiber which is assumed to be connected with it near its middle point. Text-books of histology[1] sometimes refer to the possible innervation of a single muscle-fiber by two or more nerve-fibers, but the impression is usually conveyed that this is an atypical condition. Physiologists have pointed out that the complete involvement of a muscle-fiber in the process of contraction must be secured more promptly when stimulation is made to take effect at two places than when it is restricted to one. But a simple calculation shows that any such gain in speed of developing contraction can be only slight even if the spacing of the myoneural junctions is ideal. Other aspects of reduplicated innervation brought out some years ago by Agduhr[2] have been too little regarded.

This observer discovered that in cases where a muscle in the leg of a mammal can be made to contract by stimulating either of two motor nerve-roots it may develop nearly as much tension in response to the excitation of one root as when both are stimulated at the same time. This would not be the case if each fiber in the muscle could be reached by one and only one nerve-path. The alternative, Agduhr considered, must be an organization of the motor system such that the same muscle-fibers can be called into action by distinct efferent elements. The arrangement indicated he has denominated plurisegmental innervation.

Agduhr sought and found histological evidence of such a relation. Making use of cats and rabbits he performed experiments in which the principle applied was one of differential degeneration. After sectioning a certain motor nerve-root, he kept the animals alive for from 58 to 144 hours. Postmortem preparations of particular muscles then showed normal and partially degenerated nerve-fibers in the same fields. Again and again pairs of myoneural junctions were seen upon single muscle-fibers. These were not widely separated as though adapted to insure more speedy responses, but usually close together. Most significant was the fact that where two nerve-fibers were traced to endings in one muscle-fiber the criterion of degeneration showed that they were derived from separate spinal nerves.

In this communication we desire to make a preliminary report on some experiments which were originally undertaken to see whether such a type of organization is to be found in the frog as well as in the mammal. They have been fruitful of suggestions which we did not at all anticipate. The gastrocnemius lends itself conveniently to such a study. The sciatic nerve of the frog, as observed near the spinal cord, is found to be represented by three strands. Two of these generally contribute to the motor innervation of the gastrocnemius. There is considerable variation in the relative size of these two bundles of fibers, but in many cases they are nearly equal. When this is true, it has been our experience that the contractions of the selected muscle evoked by stimulating the two components alternately are also of about the same magnitude. This holds for simple or tetanic, isotonic or isometric responses.

When we compare the tension developed by the gastrocnemius when one of the nerve divisions is stimulated with the tension recorded when both are excited at the same time it becomes apparent that but little is gained by calling in the second system to assist the first. In other words, Agduhr's experiment succeeds with the frog as well as with the mammal. Examples of this may be cited. Calling the two divisions of the nerve A and B, we note in

[1] Piersol, "Normal Histology," 1916, 86. Lewis and Stöhr's "Text-book of Histology," 1913, 163.

[2] Agduhr, *Anat. Anzeiger*, 1916, XLIX, 1–13; 1919, LII, 273. Also Wilson, *Brain,* 1921, XLIV, 234.