PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY

MINUTES OF THE WASHINGTON MEETING, APRIL 25 AND 26, 1924

The 127th meeting of the American Physical Society was held at the Bureau of Standards, Washington, D. C., on April 25 and 26, 1924. The President of the Society, Professor Charles E. Mendenhall, presided. Morning and afternoon sessions were held with an attendance of about three hundred.

On Friday evening the Society held an informal dinner commemorating the 25th anniversary of its founding. The speakers were M. I. Pupin, Henry Crew and R. A. Millikan. The dinner was attended by 186 members and guests.

The regular meeting of the Council was held on Friday, April 25, 1924. The following were elected to Membership: Samuel K. Allison, Colin Barnes, Charles H. Burr, W. P. Dobson, G. H. Glidden, Frederick R. Gorton, Ralph de L. Kronig, John T. Lay, Donald G. MacGregor, A. Appleton Packard, Mark L. Raymond, Charles H. Thomas, Arthur P. R. Wadlund, Arthur H. Warner, Richard H. Wilson, J. G. Winans.

The regular scientific session consisted of 90 papers, abstracts of which are given on the following pages. Abstracts 8, 19, 23, 27, 30, 46, 54, 55, 60, 63, 83, 86 and 89 were received too late to be put in the program, and these and 12 other papers were read by title. An **Authors Index** will be found at the end.

HAROLD W. WEBB, *Secretary.*

ABSTRACTS OF PAPERS

1. The width of the K absorption discontinuity in silver. F. K. RICHTMYER and R. C. SPENCER, Cornell University.—Several observers have found that the discontinuity in the x-ray spectral energy distribution curve, due to the introduction of an absorber into the beam, shows a "structure." Using the method of analysis discussed at the New York meeting (Feb. 1924) in connection with the width of spectral lines, it can be shown that, if we have a perfect crystal, a target with a uniform energy distribution, and a slit system of angular width α, then, if the absorber has a *perfectly* sharp discontinuity, showing no structure, (1) the width of the *observed* discontinuity should be equal to α, and (2) the shape of the energy curve through the discontinuity should be made up of two parabolas. Conclusion (1) has been verified

experimentally, from which it follows that, within the limits of error of measurement, the absorption discontinuity is perfectly sharp and shows no structure. Conclusion (2) has been verified so far as data permit. This work has been carried on by aid of a grant from the Heckscher Research Council of Cornell University.

2. The reflection of characteristic bromine x-radiation by a crystal of potassium bromide. S. K. ALLISON and WILLIAM DUANE, Harvard University.—The spectrum of x-rays from a molybdenum target tube operated at 63,000 volts and 2 m.a. has been obtained by reflection from the (100) planes of a small KBr crystal. In addition to the characteristic Mo K-series peaks which occur in the first 4 orders, peaks appear at angles calculated for the Br K-spectrum in the first 3 orders. Mo $K\gamma$ and $K\beta$ are separated in the second and higher orders, Mo $K\alpha_1$ and $K\alpha_2$ in the 3rd and 4th orders. In the third order Br $K\gamma$ and $K\beta$ are separated, but the Br $K\alpha$-doublet is not resolved. The resolving power for the Br lines is less than for those of Mo, but increases more rapidly for Br than for Mo as the order increases. The sharpness and definiteness of the Br reflections decrease markedly with increase in the width of the *ionization chamber* slit, while the widths of the Mo peaks are much less affected. This, at least partially, explains the negative results recorded by Mie and Walter, who have recently attempted to obtain photographic evidence of this phenomenon. The intensities of the Br lines apparently decrease much less rapidly with increasing order than those of the Mo lines.

3. Evidence as to the mechanism of characteristic radiation. GEORGE L. CLARK and WILLIAM DUANE, Harvard University.—New experiments on the reflection of x-rays characteristic of iodine by crystals of KI (a fact discovered by the authors two years ago) furnish evidence as to the optimum conditions for its detection and its fundamental mechanism. (1) The iodine spectrum through 5 orders from the (100) planes of KI, originally obtained with the ionization spectrometer, was completely verified. (2) The primary beam from a tungsten target at 68,000 volts passed through 1 mm of copper before striking the KI crystal. Experiments under these conditions with a calcite crystal show that the spectrum at 0.3737 A (the critical absorption wave-length of iodine) has negligible intensity, agreeing with the calculation from the absorption coefficient that 1 mm of copper reduces the intensity of a ray with a wave-length between the iodine $K\beta$ and $K\alpha$ lines to 1/10,000 of its value without the screen. In the resulting KI spectrum the strong absorption due to iodine no longer appears, but the iodine emission lines are definitely present, showing that the phenomenon is probably not due to resonance or selective reflection. (3) Experiments to define the conditions necessary for obtaining photographic evidence of the characteristic iodine reflection, notably a narrow slit in front of the plate, are described.

4. The ionization produced by x-rays in small ionization chambers. HUGO FRICKE and OTTO GLASSER, Cleveland Clinic Foundation.—The ionization produced by x-rays in a small ionization chamber is due to the secondary fast electrons partly from the walls and partly from the air of the chamber. The contribution of the walls is a function of the ratio of the mass absorption of the x-rays to the mass absorption of the secondary fast electrons in the material of the walls. Measurements have been made on chambers with a volume of 1 cc made of different pure elements (lighter than copper) and their salts, using x-rays of varying quality. From the obtained data the relative coefficients of true mass absorption of x-rays can be calculated. It is found that the true mass absorption is of two types, one proportional to the third power of the atomic number and one independent of the atomic number, the dominance of the latter type increasing in inverse relation to the wave-length. The results agree with Compton's recent theory of absorption and scattering of x-rays. A chamber made of ammonium nitrate +1 per cent potassium chloride gives the ionization current of a chamber having

walls of atmospheric air, and may be used as a standard ionization chamber in investigations of the biological action of x-rays.

5. A new form of current-measuring instrument of extreme sensitivity. ROY KEGERREIS, Mayo Clinic, Rochester, Minn.—The charged particles of an ionized gas are attracted to or repelled from the plates of an ionization chamber. Air currents are set up within the ionization chamber when this action takes place as was shown by Zeleny in 1898. This circulation phenomenon, which is commonly called "electric wind," is employed, in the present instance, to move the vane of a suspension system. The plates of the ionization chamber are perforated with numerous holes. Suitable passages are provided in order to cause the air currents from the ends of the ionization chamber to impinge upon a vane and thus twist the suspended system. Alpha rays from polonium are used to produce the ionization. It is essential that the conditions of ionization be such as to insure operation on the straight part of the saturation curve. The instrument has a sensitivity much higher than that obtainable with any type of galvanometer and is about equal to that which can be realized with a quadrant electrometer when shunted by a high resistance. It can of course also be used as a voltmeter. The same principles of construction may be adapted for extremely high voltage measurements by making use of similar attendant circulation phenomena in insulating fluids. It is necessary that the various parts be highly insulated from each other and so the preliminary working model was made from carvings in solid paraffin.

6. The scattering of x-rays. I. MAIZLISH, University of Minnesota.—In this paper the theories of Thomson, Debye and Schott are briefly summarized. The large-electron theory of A. H. Compton is criticized, and it is shown, among other things, that it leads to a value of m which is only 1/1000 of that obtained from the values of e and (e/m). An attempt is made to bring into harmony the known facts of x-ray scattering on the basis of classical electrodynamics. It is shown that if we assume the electron to be made up of a large number of parts and introduce into our equations of motion of these parts a term which is akin to friction in ordinary dynamics, we will be able to explain the observed diminution in the scattering coefficient when short wave-lengths are used. For long wave-lengths this will give the same scattering as Thomson's theory. But the observed asymmetry cannot be explained on this basis. It was next thought desirable to combine Debye's theory with our modified electron and to discuss the results. It appears impossible to adhere to classical electrodynamics and explain all known facts of the scattering of x-rays. (See J. Franklin Inst. May, 1924.)

7. The scattering of polarized x-rays by paraffin. G. E. M. JAUNCEY and H. E. STAUSS, Washington University.—G. E. M. Jauncey has shown (Phys. Rev., **23,** 313, 1924) on the basis of a corpuscular theory that the angle of scattering for complete polarization should be given by $\cos \phi_p = \alpha/(1+\alpha)$ where $\alpha = h/mc\lambda$. This theoretical prediction has been tested experimentally. X-rays were scattered from a paraffin block at about 88° and these polarized x-rays were scattered from a second paraffin block. The scattering from the second block was measured at different angles in a plane containing the electric vector. With x-rays of effective wave-length 0.25 A (measured by absorption in Al) a minimum was found at about 87° 30′, the theory predicting 84° 47′. The minimum reading, however, was not zero, this being due to multiple scattering, angular width of the primary rays, etc. These extraneous effects make the result somewhat uncertain. The experiment was repeated with x-rays of effective wave-length 0.54 A, the minimum then coming at about 90°, the theoretical value being 87° 30′. There seems therefore to be an experimental shift of the polarizing angle to the small angle side of 90° which increases as the wave-length decreases. The shift is less than the theory demands but is of the same order of magnitude.

8. The wave-length of molybdenum Kα rays scattered by light elements.—ARTHUR H. COMPTON and Y. H. WOO, University of Chicago.—The x-rays from a water-cooled molybdenum tube were scattered by a radiator placed about 3 cm from the focal spot. In one set of experiments, the following series of substances were used successively as radiators: metallic lithium, amorphous boron, graphite and water. These radiators were prepared in the form of cylinders of 8 mm diameter, the amorphous boron and the water being held by an oiled paper wall about .05 mm thick. The radiators were clamped successively in the same position, and scattered the rays at $128 \pm 2°$. The spectra observed showed in each case a faint line identical ($\pm .001$A) in wave-length with the primary Kα line, and a stronger line of wave-length greater by the amount $.039 \pm .001$A, as demanded by the quantum theory of scattering. Thus the quantum formula holds for the elements Li, B, C and O, contrary to the conclusion of Clark, Duane and Stifler. Experiments using successively sugar crystals and wood, which have about the same chemical composition, gave spectra in which the relative intensities of the modified and the unmodified lines were nearly identical, showing that their relative intensity does not depend upon whether the radiating substance is crystalline or amorphous.

9. A general quantum theory of the wave-length of scattered x-rays. ARTHUR H. COMPTON, University of Chicago.—The quantum theory of the change of wave-length of x-rays when scattered is extended to the case of scattering by bound electrons, by taking account of the energy spent in removing the electron from the atom in addition to that spent in setting the electron in motion. If the scattering electron and the residual atom can acquire any velocities consistent with the conservation of energy and momentum, the change of wave-length lies between $\lambda^2/(\lambda_s - \lambda)$ and ∞, where λ is the incident wave-length and λ_s is the critical ionization wave-length for the scattering electron in its original orbit. This result is identical with that of Clark and Duane's theory of tertiary radiation, and accounts adequately for all the observed modified lines. A restricted form of the theory is based on the assumption that the final momentum possessed by the residual atom is that acquired during the absorption from the incident beam of the energy hc/λ_s required to remove the electron from the atom. The resulting change in wave-length is $\lambda^2/(\lambda_s - \lambda) + \gamma$ vers ϕ, where ϕ is the angle between the primary and the scattered ray, and $\gamma = h/mc = .0242$ A. This formula describes accurately the spectra observed for rays scattered by the lighter elements.

10. The reality of the Compton effect. J. A. BECKER, E. C. WATSON, W. R. SMYTHE, R. B. BRODE and L. M. MOTT-SMITH, California Institute of Technology.—X-rays coming from a water-cooled molybdenum tube fall upon a plane sheet of aluminum placed about 6 cm from the target. The scattered radiation is analyzed by means of a calcite crystal in a Seemann spectrograph about 1 cm from the scatterer. The photographic plate is 42 cm from the crystal. The tube is operated at about 35,000 volts r.m.s. and 25 m.a. The angle between the incident and scattered rays is about 100°. A comparison spectrum of the molybdenum rays analyzed directly is also taken on the same film as the scattered radiation. The comparison spectrum shows the α_1, α_2, β and γ lines of Mo. A 60 hour exposure for the scattered radiation shows: (a) sharp α_1 α_2 lines clearly resolved and shifted by .027 A—this shift agrees very well with the Compton theory for 100°; (b) very faint unshifted α_1 α_2 line; (c) faint but unmistakable β line shifted .027 A. The resolved shifted α doublet cannot possibly be accounted for as tertiary radiation. This is then unambiguous evidence for the reality of the Compton effect.

11. Crystal structures and densities of oxides of the 4th group. WHEELER P DAVEY, Research Laboratory, General Electric Co.—(1) TiO_2 shows a base-centered tetragonal structure of Ti; $a = 4.582$ A; $a/c = .650$ (compare with Groth .6439). The

positions of the oxygens are indeterminate. Density of TiO_2 = 4.226 (compare with Groth 4.283).—(2) SnO_2 has a structure like TiO_2; a = 4.718 A; a/c = .670 (Groth .6726); density 7.036 (Groth 6.992 – 7.044).—(3) CeO_2 has a face-centered cubic lattice of Ce; a = 5.405 A; density 7.195 (Groth 6.93 – 7.99). The oxygens probably have the same spacing in CeO_2 that the fluorines have in CaF_2.—(4) PbO_2 gives a diffraction pattern which may be interpreted equally well as a TiO_2 structure, or as a body-centered tetragonal structure of Ti with undeterminate O. In either case a = 4.949 A and a/c = .685 (compare with Groth .676); the density is 9.498 (Groth 8.56).—(5) ThO_2 has the same structure as CeO_2; a = 5.585 A; density = 9.998 (Van Nostrand 9.876).—A diffraction pattern was obtained from ZrO_2 but so far no solution has been found. GeO_2 has not been tried. The only other member of this group which is crystalline at room temperatures is SiO_2. Infusorial earth heated to cone $11\frac{1}{2}$ is a hexagonal close packed lattice (a = 6.80 A; a/c = 1.65) with apparently 6 SiO_2 per unit crystal, giving a density of 2.552. The exterior form given in Groth for tridymite can be derived from this lattice. The results of McKeehan for quartz are confirmed.

12. The orientations of electrodeposited crystals in iron, nickel, copper and zinc, as determined by x-rays. RICHARD M. BOZORTH, Research Laboratories of the American Telephone and Telegraph Co. and Western Electric Co., Inc., New York (Introduced by H. D. Arnold).—It is found that, whereas the crystals in electrodeposited copper and zinc are oriented at random, the crystals in iron and nickel deposits show preferred orientations. In nickel deposits the (100) planes tend to be parallel to the polished brass surface on which the deposits are made. In iron the (111) planes tend to have the same aspect. The method of investigation is to allow a beam of approximately monochromatic x-rays, having a circular cross-section, to fall obliquely on a foil stripped from the deposit, producing a characteristic pattern on a photographic plate placed normal to the incident beam a few centimeters behind the foil. A chaotic arrangement of crystals gives complete circles, as in the ordinary powder method, the intensity being constant along any one circle except as modified by absorption in the film. A preferential orientation is indicated by intensification at definite positions on the circles, different for each. The interpretation of the patterns is made in accordance with the geometrical analysis of Polanyi.

13. Apparatus for determining the orientation of single crystals. WHEELER P. DAVEY, Research Laboratory, General Electric Co.—The determination of the orientation of a single crystal requires a new type of apparatus. The crystal is mounted so that it may be rocked back and forth through an angle of about 45°. The surface to be examined is mounted at some predetermined angle χ to the direction of a beam of monochromatic x-rays when the crystal holder is at one end of its oscillation. The crystal holder carries a photographic film on a cylindrical holder whose axis is the axis of rotation of the crystal so that the film rotates through the same angle as the crystal. Behind this film is a stationary cylindrical film mounted in the usual way. This stationary film serves to identify the reflecting crystal planes, for it receives a diffraction pattern of the ordinary type which is measured in terms of the total angle of deviation of the beam. This angle is twice the grazing angle θ. Measurements on the rotating film give the angular rotation ρ at the instant of reflection. $\rho = \theta + \chi + \varphi$ where φ is the angle between the surface of the specimen and the plane which causes the reflection. The angles χ and φ may be either positive or negative depending upon experimental conditions.

14. The universal applicability of x-ray doublet laws in the field of optics. I. S. BOWEN and R. A. MILLIKAN, California Institute of Technology.—The relativity doublet formula is found to predict exactly the p, d, and f term doublet-separations in the succession of similar atomic structures Li(I), Be(II), B(III), C(IV), N(V); also in

Na(I), Mg(II), Al(III), Si(IV), P(V), S(VI); also in B(I), C(II), N(III), O(IV); also in Al(I), Si(II), P(III); also in Be(I), B(II), C(III), N(IV), O(V); also in N(II) and O(III); also in Mg(I), Al(II), Si(III), P(IV). All of these types of ionization have been definitely found in "hot-spark" spectra. The Hertz irregular doublet law has been found to predict the difference between the s and p terms and the p and d terms in optical spectra.

15. Difficulties with the Bohr atom. R. A. MILLIKAN and I. S. BOWEN, California Institute of Technology.—Our experimental work reported in the preceding paper constitutes an interesting step in the direction of the simplification of our working formulas; it makes possible a definite correlation throughout of x-ray and optical levels; it also brings about complete uniformity in the assignment, hitherto usually contradictory, of inner and azimuthal quantum numbers in these two fields. On the other hand it appears to require either the abandonment of the relativity explanation of the regular doublet, or else the abandonment of the familiar assignment of the s, p, d, f, etc. terms to the azimuthal quantum numbers 1, 2, 3, 4, etc., respectively.

16. Quantum defect and atomic number. LOUIS A. TURNER, Princeton University.—The square root of the quotient of the Rydberg constant and a term value gives the effective quantum number. Subtracting this from the true quantum number gives the quantum defect. This approaches a limiting value for the higher terms. It is found that this limiting quantum defect is a linear function of the atomic number for corresponding series, for elements of the same chemical sub-group, provided Bohr's quantum numbers be increased for elements of atomic number above 28. The quantum numbers for the normal orbits in Rb and Cs are taken to be 6_1 and 8_1, respectively, and similar changes made in all of Bohr's numbers. The slopes of the lines are all nearly the same. These relations apply only to series corresponding to penetrating orbits. The s lines of elements of different chemical nature and spectral type lie close together, indicating that the quantum defect depends primarily upon atomic number and secondarily upon particular atomic structure. The p lines for all neutral elements lie approximately 0.50 below the s lines. The quantum defects for ionized atoms are less than those of the corresponding neutral atoms and the $s-p$ difference is less, the higher the degree of ionization.

17. Soft x-ray levels and the Bohr scheme of atomic structure. F. L. MOHLER, Bureau of Standards.—A wide range of published data on critical radiation potentials of solids and gases has been used to trace the energy levels of atoms from the optical to the x-ray range. The results are in general consistent with the conclusions of Bohr and Coster as to the probable course of soft x-ray levels on the Moseley diagram. Some of the critical potentials evidently measure excitation without ionization, but contrary to the views of Rollefson and McLennan there is some evidence that most of the more prominent critical potentials measure ionization potentials.

18. Fine analysis of the Stark effect for Hβ and He λ4686. J. STUART FOSTER, National Research Fellow, Yale University.—Seven of the components which Stark has recorded for Hβ at 104 kv/cm are not predicted by the theory. The purpose of the present investigation was to see if some of these were grating ghosts as has been commonly assumed. Many photographs taken by Lo Surdo's method show all components observed by Stark which agree with the theory, and no others. On the other hand, one photograph of the parallel components alone shows Stark's components ± 4 with even greater relative intensity than he has assigned to them. As an explanation, the writer suggests that the spurious components are produced by variations in the direction of the applied field. Thus it is believed that a part of the energy of a real perpendicular component must produce on the plate an apparent parallel component, and vice versa. This explanation is supported by accompanying analyses of He λλ4922, 4472;

and by variations in the pit formed in the cathode. The photographs also show a fine analysis of the ionized helium line λ4686 of the predicted type, but somewhat obscured by other lines. At 33 kv/cm the strong outside parallel components have a separation in excellent agreement with Epstein's theory. At 46 kv/cm the displacements of the two perpendicular components on the red side are 0.37 and 0.76 A; the calculated values are 0.33 and 0.66 A.

19. Chlorine spectrum in the extreme ultraviolet. J. J. HOPFIELD, University of California.—In this preliminary work on the ultra-violet spectrum of chlorine, when the dry gas is used to fill both the receiver and the discharge tube of the vacuum-grating spectrograph, its spectrum is found to extend to λ790, and hence the gas is not too opaque for spectrum analysis in this region. Many new strong lines have been observed and others were obtained which check with those found by Millikan using the vacuum spark method. Some of the groups of lines, on comparison with similar groups in the new sulphur spectrum (Nature **112,** 437, 1923), give strong evidence that those lines in the arc spectrum of sulphur which have not yet been classified into the series of sulphur are in reality arc lines, and that these found in chlorine are consequently Cl(II) lines. When aluminum electrodes were used, a condensed discharge brought out the aluminum lines first observed by Lyman and only recently classified into spark series by Paschen. (Lyman, Spectroscopy; Paschen, Ann. der Phys. **71,** 152, 1923.) One of the most marked features of the spectrograms is a new group of *bands of aluminum chloride* that occurs at λ2620.

20. The vacuum spark spectrum of zinc in the region λ2100-4000. R. A. SAWYER and E. J. MARTIN, University of Michigan.—The vacuum spark spectrum of zinc has been investigated with a large quartz spectrograph. The spark box was constructed of Pyrex glass. The electrodes were mounted on heavy tungsten leads which were sealed into tubes that turned in ground joints so as to permit adjustment while sparking. A high vacuum and the glass insulation permitted the use of a very violent, condensed spark. Of the arc spectrum only the subordinate triplets $2p-3s$, $2p-3d$, and $2p-4d$ appeared with considerable intensities. All the other arc lines were weak or absent. All the spark lines given by Exner and Haschek appeared. In addition about 250 new wave-lengths have been recorded. About 100 of these were among the strongest lines in the spectra and have been measured on three or more plates. The new lines were grouped to some extent in the regions λ2400-2700 and λ3500-4000. As yet no additional lines have appeared in the region λ2000-2200 although the known lines in this region were strongly recorded. The work is being extended into the visible region.

21. The infra-red line spectra of zinc and cadmium. H. M. RANDALL and W. N. ST. PETER, University of Michigan.—In the work described the authors give the results of their investigations of the spectra of zinc and cadmium in the region between 1μ and 5μ. The arrangement and methods in this work are similar to those employed by Randall and Barker in 1919 with the following modifications. The source was an open carbon arc with 100 amperes capacity at 220 volts, the metals under investigation being inserted in the cored positive electrode. The diffraction grating was of the echellette type and was made by Barker at the University of Michigan. This grating has 7200 lines to the inch and is ruled so as to have its maximum energy in the region around 2.5μ. The effectiveness of this type of grating has been demonstrated. A list of new lines is given. Most of these have been identified by means of the combination principle with an accuracy of 5 A or less. Graphs indicating the changes in energy levels are included.

22. The spectrum of "nebulium." HARVEY B. LEMON, University of Chicago.—The spectra of the nebulae as summarized by Wright (Lick Observatory Publications, Vol. 13, 1918) contain 70 lines, which include, in addition to the lines of hydrogen,

helium, and ionized helium, 35 lines of unknown origin. These, together with 11 others not included in Wright's paper, and with the exception of one line whose identification as distinct from a helium line is uncertain, have been found to lie within the accuracy of measurement upon five branches of a parabola in which an index number is plotted as ordinate against wave numbers as abscissa. These parabolas open toward the red, and all have axes of approximately the same small inclination to the wave number axis. Of very great significance also may be the fact that 13 lines of ionized helium out of a total of 18 lie somewhat irregularly distributed on the same curve, and that the lower branches of all five curves by large extrapolation may intersect in the vicinity of the position of the first line $H\alpha'$ of the spectrum of ionized helium, λ10,126.6 A. The formulation was first made on the basis of the 35 lines given by Wright. The 11 others, on which information was subsequently obtained, were found to be taken care of on the same curves; and this is the chief reason why these results are thought to be of considerable significance.

23. An apparently new spectrum associated with spectra of unknown origin in the tails of certain comets. HARVEY B. LEMON, University of Chicago.—The tails of comets Daniell and Morehouse have been found to show band spectra of unknown origin not occurring generally in cometary nuclei, and these spectra have been reproduced in the laboratory by Fowler and by Merton, who attribute them, we believe quite properly, to carbon or some of its compounds. Merton has found that the presence of helium greatly facilitates their production. The new spectrum, which is the subject of this paper, lies in the ultra-violet region and could, therefore, never be observed in comets' tails directly. It never fails to make its appearance under a wide variety of conditions, all of which bring out the visible comet tail bands. The bands of which this spectrum is composed possess an unusually simple structure, and they have been produced with sufficient intensity to enable a photographic record to be made in the second order of a 21-foot Rowland concave grating. Because of the simplicity of their structure, it is hoped that an analysis along the lines of the present quantum theory of band spectra will yield important information as to the nature of the radiating molecule.

24. The line spectra of W and Ni in the afterglow of a discharge through a mixture of N_2 and A. A. G. WORTHING and R. RUDY, Nela Research Laboratory.—In a discharge through 99.8 per cent A+0.2 per cent N_2 at a pressure of 300 mm, two afterglows were obtained. With tungsten electrodes, one afterglow was orange colored. Its spectrum showed strongly the first and second groups of positive nitrogen bands. The other afterglow was blue. Its spectrum showed strongly the tungsten lines superposed on a faint background consisting of a continuous spectrum and of nitrogen bands. Both afterglows were obtained either separately or simultaneously. Low electrode temperatures and quiet discharges favor the first type. High electrode temperatures and condensed discharges with series spark gap favor the second type. In the latter case, a dark deposit probably a tungsten nitride forms on leads and glass container. With nickel electrodes the blue afterglow changed to green showing strong nickel lines. This is believed to be the first record of the excitation of the line spectrum of a highly refractory element by active nitrogen. The afterglows obtained from the argon nitrogen mixture were far stronger than those obtained in nitrogen only. No argon lines were seen during the discharge or in the afterglow.

25. The excitation of the spectra of the copper halides by active nitrogen, and the application of the isotope effect to the interpretation of band spectra. ROBERT S. MULLIKEN, Harvard University.—Active nitrogen was used to excite the spectra of CuCl, CuBr, and CuI. Probably an excited nitrogen molecule on collision with a CuX molecule either (1) excites a copper electron which in CuX_2 would act as a valence electron (result, emission of CuX bands), or (2) dissociates the molecule and excites the copper

atom (result, emission of copper arc lines), or (3) forms copper nitride (shown by chemical tests, although apparently no spectrum results). Examination of the CuX bands reveals the expected vibrational isotope effect in all three halides. With this effect as a guide, each spectrum proves to consist of several partly superposed band-systems. The heads of the green CuI bands are given ($n'=0,1.....8$; $n=0,1.....12$) by: $Cu^{63}I$, $\nu=19{,}708.3+211.9n'-2.35n'^2-264.5n+0.69n^2$; $Cu^{65}I$, $19{,}708.3+209.7n'-2.30n'^2-261.8n+0.68n^2$. These bands have a characteristic intensity distribution probably typical of the band spectra of many salts, and such as might be expected for an inharmonic oscillator.

26. The band spectrum of water-vapor. WILLIAM W. WATSON, University of Chicago.—Results both of an experimental and theoretical nature lead to the conclusion that the ultra-violet water-vapor bands have their origin in the hydroxyl ion rather than the water molecule. For both hydrogen and oxygen are necessary for their production, and it is impossible to excite this spectrum with the weakest electrodeless discharge through flowing water-vapor without causing the appearance of the Balmer hydrogen lines, thus indicating that the H_2O is easily decomposed into OH and H. Furthermore, the application of the quantum theory of band spectra to the fine structure of the λ2811 and λ3064 bands gives information favoring OH as the carrier. The λ2811 band has been photographed with high dispersion and every line has been assigned to a parabolic series. Departures of the relationships between the lines of these bands from the predictions of the simple quantum theory of band spectra have been found. The moment of inertia of the molecule is not a constant quantity, but varies with its speed of rotation. Two types of OH molecules appear to exist; one with but seven electrons, the other with the full complement of eight electrons.

27. The band spectrum of mercury and the dissociation of hydrogen by excited mercury atoms. K. T. COMPTON and LOUIS A. TURNER, Princeton University.—We have found that the band spectrum of mercury, the three strongest bands of which are of wave-lengths 4219, 4017, and 3728, appears strongly in the striated positive column of a hot cathode Geissler discharge in a mixture of hydrogen and mercury vapor, disappears when the hydrogen is pumped out, and is roughly proportional in intensity to the amount of hydrogen present. This indicates that the spectrum is emitted by a mercury hydride, in confirmation of the predictions of Kratzer and of Mulliken based on a study of the line structure of the bands from the point of view of the quantum theory. The emission is strongest in those parts of the discharge where other experiments indicate the highest concentration of excited mercury atoms. Apparently this spectrum results from an action of excited mercury atoms and not from the excitation of already existent hydride molecules. We suggest the hypothesis that the excited mercury atom reacts with a hydrogen molecule to form both a hydrogen atom and an excited hydride molecule which then emits the band spectrum, rather than simply dissociating the hydrogen molecule, as suggested by Cario and Franck. Our explanation meets fewer difficulties in the consideration of thermal equilibrium.

28. A band of unusual structure probably due to a highly unstable calcium hydride molecule. ROBERT S. MULLIKEN, Harvard University.—In the calcium arc in hydrogen at low pressure, an isolated band occurs in association with the lines of neutral calcium. Thus it is probably due to a compound of an excited (not ionized) calcium atom. The wide spacing of the lines and absence of appreciable isotope effect practically assure its hydride origin. The simple structure indicates a diatomic molecule. The lines of the two branches can be represented by the formula (obtained by term isolation), $\nu=28{,}358.43\pm2.365-2.311\ m\pm9.603\ m+0.566m^2\mp0.00342m^3-0.000662m^4$, where $m=\frac{1}{2},\ 1\frac{1}{2},....9\frac{1}{2}$ for the positive branch (upper signs) and $1\frac{1}{2},\ 2\frac{1}{2},.....11\frac{1}{2}$ for the negative. (Formulas with integral quantum numbers are also possible.) The lines

$m_{pos.}=9\frac{1}{2}$ and $m_{neg.}=11\frac{1}{2}$, which should both correspond to $m'=10\frac{1}{2}$ ($10\frac{1}{2}$ quanta of rotation in the *initial* electronic state of the molecule), are, however, both displaced by -0.62 units; and after this there are *no more lines* in either branch. The obvious and most probable explanation is that the molecules in the excited state begin to expand rapidly by centrifugal force (the extraordinarily high coefficients of m^3 and m^4 in the formula also indicate such a tendency) near $m'=10\frac{1}{2}$, and cannot exist with higher values of m'.

29. The 23 volt arc in helium. C. B. BAZZONI and J. T. LAY, University of Pennsylvania.—New and satisfactory photographs with and without neutral tinted wedges have been taken in mercury free helium at 23 volts and at 26 volts, i. e. below and above the normal ionization point. A hollow nickel anode is used. A non-inductive series resistance of 10,000 ohms is introduced to prevent oscillations and the consequent production of undetected voltages. The 23 volt spectrum is markedly different in appearance from that taken at 26 volts with the same bombarding current. Although at 23 volts crossed orbit lines of the lower order numbers are present, especially 5016 which is strong, the coplanar lines are notably more conspicuous. It is a fair statement of the facts to say that the 23 volt arc is predominantly coplanar.

30. Theory of normal and abnormal low voltage arcs. K. T. COMPTON and CARL ECKART, Princeton University.—A continuation of the study of the "abnormal" low voltage arc (one in which current and voltage are oscillating) which was described at the preceding meeting of the Society has led to a fairly complete physical interpretation of the phenomena there described, including the oscillations observed under certain conditions. The arc current i and voltage V must satisfy two conditions. The first, imposed by the external circuit, is given by $V=E-Ri$, where R is the series resistance and E the impressed e.m.f. The second depends upon internal characteristics of the tube, involving space charge, critical potentials of the gas, filament saturation current and geometrical features. These latter conditions are given at various stages of current as E is increased (1) when V is less than the minimum radiating potential V_r; (2) when V exceeds V_r but is less than the ionizing potential V_i; (3) when V exceeds V_i. It is shown that the nature of cumulative and direct ionizations causes a discontinuous decrease in V and increase in i at some voltage greater than V_r. Oscillations set in when the space charge around the filament becomes positive and the increase of current to saturation value causes the voltage to drop below V_r, thus again diminishing the current, and so on. This interpretation is supported by spectroscopic evidence, observations on the heating of the filament, and considerations based on the life of excited atoms.

31. Absorption of helium radiation by helium. A. LL. HUGHES and F. E. POINDEXTER, Washington University.—Helium radiation was excited by bombarding helium atoms by electrons of a definite velocity. The radiation fell upon a nickel plate 30 cm away, in the same vacuum, and produced a photo-electric effect which was measured by an electrometer. If the energy radiated is proportional to the number of impacts between the electrons and atoms, then the photo-electric effect should be proportional to the number of impacts provided that there is no absorption. Assuming that the deviation from proportionality is due to absorption, the absorption coefficient can be calculated. The numerical value of the absorption coefficient β in the exponential factor $e^{-\beta pd}$ refers to 1 cm distance and 1 mm pressure. For radiation excited by electrons of 22.8 volts energy, the maximum value of β was about 6.5 and decreased with increasing pressure, suggesting that the radiation was heterogeneous so that the more absorbable radiation was filtered out first. For radiation excited by electrons of 26.8 volts energy, the maximum value of β was about 2.5. For radiation excited by 91 volts, the absorption could not be detected by this method within the range of pressures used (.001 to .018 mm).

32. Critical potentials and spectra of arsenic, antimony and bismuth. ARTHUR E. RUARK, F. L. MOHLER, P. D. FOOTE, and ROY L. CHENAULT, Bureau of Standards.—The Bi lines 3067, 2276, 2230, 2228 and 1954 A were photographed in absorption. Below 1000°C As and Sb give only band and continuous absorption. Bi has groups of absorption bands between 2874 and 2672 A and below 2205 A. Foote, Rognley, and Mohler measured the critical potentials of these elements, but data were published only for As. The voltages of inelastic collision and ionization are: As, 4.7 and 11.5; Sb, 1.7 ± 0.5 and 8.5 ± 1; Bi, 2.0 and 8.0. We photographed thermionic discharges in Bi at potentials from 4 to 60 volts. Spark spectra appeared at 14 ± 1, 25 ± 5, and possibly at 45 ± 5 volts. The resonance potential corresponds to several weak lines. The raies ultimes 3067 and 4722 A appear at 4 volts. The critical potentials of the other elements are apparently related to the atomic spectra. The arc spectra are characterized by doublets. The lowest orbits in As are of *d*-type; in the other elements their character is unsettled. In each element the lowest orbits form a compact group well separated from all others. Some bismuth lines have fine structures which will probably require the introduction of a new quantum number, called the fine quantum number.

33. Intensities in the argon spectrum. PERCY LOWE and D. C. ROSE, Queen's University, Canada (introduced by A. Ll. Hughes).—A quantitative measurement has been made of the variation in the intensity of 50 argon lines, excited by electronic impact, as the energy of the exciting electrons varied from 24 to 140 volts. The apparatus consisted of a large three-electrode tube through which pure argon was continually passed at a constant low pressure. A constant current was maintained between filament and plate; the grid and plate were kept at the same potential, and the spectrum of the gas in the field-free space between these photographed. For measuring intensities, the neutral wedge method was used. The results show a division of the argon lines into two main classes corresponding in general to the red and blue spectra. Those in the latter class first appear at slightly over 40 volts, increase rapidly to a maximum at about 65 volts, then decrease slightly and remain fairly constant at higher voltages. The lines of the red spectrum are subdivided into two groups in one of which the intensity decreases steadily above 30 volts while in the other, after small variations at low voltages, it remains practically constant. This work was carried out by means of a grant from the Honorary Advisory Council of Canada.

34. The application of ultra-violet photographic photometry to problems of atomic structure. GEORGE R. HARRISON, National Research Fellow, Harvard University.—Applications of the correspondence principle emphasize the need for more exact methods of determining light intensities. The present work is an attempt to determine the variation with wave-length of the series limit absorption in alkali metal vapors, and to analyze isotopes quantitatively through their band spectra. The method used is generally applicable and increases the accuracy of measurements in the region 2100-5000 A. Little being known of the characteristics of photographic emulsions exposed to light below 3500 A, curves are being determined giving the variation of density with wave-length, time of exposure, and light intensity in numerous standard emulsions. Three-dimensional "characteristic surfaces" show the features of each emulsion in regard to sensitivity, contrast, scale, and obedience to the numerous suggested photographic laws. An electric absorption furnace is an integral part of the sensitometer. Twenty-two complete spectra are photographed on one plate, giving several values for each point and minimizing emulsion irregularities. A rotating disk spark gap of cadmium furnishes a steady source, intensity being controlled by a thermopile and carefully calibrated screens of wire mesh. Results are given in numerous curves and tables.

35. Note on the quenching of the fluorescent radiation in mercury vapor. JOHN T. TATE, University of Minnesota.—It has recently been suggested by G. Mie that atoms not only remain in the excited state for a mean time τ but also take a finite time to pass

from the excited to the normal state. He suggests the possibility that the energy J of the excited atom decreases exponentially during radiation according to the relation $J=J_0e^{-t/\tau'}$ where τ' may be called the transition time. It is further assumed that atomic collisions may de-excite the atom both before and during the radiation process. Applying these assumptions to the fluorescence of a gas it may readily be shown that the ratio R of the fluorescent to the incident radiation intensity is given by (1) $R=1/(1+\tau/T)\ (1+\tau'/T')$ where T and T' are the mean times between de-exciting collisions for the excited but non-radiating atoms and for the radiating atoms respectively. If, as Cario assumed, the act of radiation is instantaneous ($\tau'=0$) this becomes (2) $R=1/(1+\tau/T)$. This expression differs from the one derived by Cario. The experimental results of Wood and of Cario on the quenching of the fluorescent radiation from mercury vapor by the addition of foreign gases satisfy within the probable error an expression of type (2). Indeed they show that if we assume (1) then either τ/T or τ'/T' is a very small fraction, of the order of .01, of the other.

36. The luminous efficiency of chemi-luminescent reactions. ELLIOT Q. ADAMS, Nela Research Laboratory.—The efficiency of light production by chemical reactions proceeding at ordinary temperatures appears not to have been measured hitherto. Such a measurement was made in the case of phosphorus by saturating a stream of specially purified (atmospheric) nitrogen with phosphorus by bubbling through saturated solutions of phosphorus in refined cottonseed oil with finely divided phosphorus in suspension, and allowing the saturated gas to escape into the air. The intensity of the "flame" was matched by illuminating an annulus of filter paper with a miniature lamp bulb, sliding on a vertical rod. Approximate color match was secured by a suitable green light-filter. The data of Centnerszwer on the vapor pressure of phosphorus, together with the heat of combustion of phosphorus and the rate of flow of nitrogen, gave the energy input. The ratio of light production to energy input was found to be slightly more than one lumen per kilowatt, and not to differ materially at 25° and at 40°. Preliminary measurements of a similar kind have been made for the luminescence accompanying the oxidation of pyrogallol by hydrogen peroxide. Similar measurements will be made for other photogenic reactions.

37. The wave-lengths of fading and of absorption of the alkali chlorides colored by x-rays. P. L. BAYLEY, Cornell University.—Halite and sylvite colored by x-rays have strong absorption bands with maxima at .46μ and .55μ respectively (Phys. Rev. **21,** 716, 1923). The *color absorption* (absorption of the uncolored material minus the absorption of the colored material) of halite begins at 0.3μ and extends to 1.3μ. Placed in the spectrum, such substances fade over a very narrow region at first but the region spreads quickly to fairly definite boundaries beyond which fading can not be observed even after exposures 100 times those necessary to completely fade the first region. For four alkali chlorides, the regions of most rapid fading are: NaCl, 0.50μ; KCl, 0.61μ; CsCl, 0.63μ; and RbCl, 0.68μ. For NaCl and KCl these regions are shifted to the long wave-length side of the peaks of the color absorption curves of halite and sylvite because of the greater energy in the red end of the spectrum used. The curve given by the product of the ordinates of the incident energy curve (calculated) and of the color absorption curve of the material has a maximum at .500μ for halite and at .595μ for sylvite, which wave-lengths are nearly those of most rapid fading. Thus it seems probable that such materials are faded by the energy gained by their color absorption alone.

38. The problem of gas-opacity. JOHN Q. STEWART, Princeton University Observatory.—A survey of the general problem of gas-opacity is made, including a unified treatment of the subject, with references to the important researches dealing with dispersion, Rayleigh scattering, "resonance" scattering and selective absorption, the opacity of an ionized gas, and the transmission of radiation through a gas. The value of classica

electromagnetic theory in the treatment of these problems is discussed; and the tentative attempts which have been made to bring these matters under the quantum theory are indicated. (The study of opacity is related to the calculation of *intensities* of emission lines; to date the chief developments of quantum theory, and the greatest accumulations of experimental data, have been, however, in connection with *wave-lengths*.) The principles formulated are applied to certain astrophysical problems.

39. Note on the electromagnetic theory of radiation pressure. W. F. G. SWANN, University of Chicago.—The paper comprises a modification of the usual derivation of the expression for radiation pressure. It proceeds from the stand-point that the total value of $\rho(E+[VH]/c)$ integrated over the absorbing or reflecting plate is zero at all times. It is made for a fixed plate, and for a plate free to move, and its object is the removal of certain logical imperfections arising, in the usual derivations, from an attempt to consider, in addition to the primary beam, only those portions of the field generated by the motions of the electrons in the plate which ultimately cooperate to produce the reflected wave in the case of a reflecting plate, or the wave of cancellation in the case of an absorbing plate.

40. Free electrons in black body radiation. G. BREIT, University of Minnesota.—It is claimed by Pauli (Zeit. f. Phys. **18,** 273, 1923) that the work of Lorentz (Report of Solv. Cong., 1911) and of Fokker (Dissert. Leiden 1913; Arch. Néerl. (3a) **4,** 379, 1918) proves that the interaction between free electrons and black body radiation is of a non-classical nature and that therefore some such theory as Compton's for the interaction must be used. An examination of the problem shows, however, that the *observable* effects of the motions of electrons are consistent with classical electrodynamics provided the radiation satisfies Einstein's condition for the fluctuation of energy. The observable radiation pressure effects give the electron the classical value of kinetic energy. The rapid vibratory motions have a non-classical kinetic energy. These motions, however, are not observed and are not the motions treated by Fokker.

41. An optical effect of electrostatic charge. A. DE FOREST PALMER, Brown University.—The phase change, produced by negative electrostatic charge, in the elliptically polarized light reflected from a speculum metal mirror was measured with the strained glass elliptic analyzer described at the Chicago meeting in December, 1920 (Phys. Rev. **17,** 409, 1921). It was found to be proportional to the square of the surface density of the charge and to depend on the surface condition of the mirror. The surface of a freshly polished mirror changes so rapidly that the effect of an electric charge is masked by other phenomena. The results reported were obtained with a surface about two years old that showed no appreciable tarnish. This surface had reached a semi-stable state in which the changes were so slow that the relation between the electric effect and the angle of incidence could be approximately determined. The phase change per unit surface density was found to be $2.78\lambda\times10^{-5}$ at incidence 55°.8. It was zero at 68°.7, about one degree above the principal angle of incidence of the uncharged mirror, and passed through a minimum, $-2.4\lambda\times10^{-5}$, at about 80°. These results are in good agreement with a theoretical formula in the form $d=Af_1(\phi)-Bf_2(\phi)$ which shows that the effect also vanishes at normal incidence and at grazing incidence.

42. Explanation of the polarization experiment of Wood and Ellett on the classical theory. JOHN A. ELDRIDGE, University of Wisconsin.—Wood and Ellett have observed changes in the plane of polarization when a tube of mercury or sodium vapor which has been caused to fluoresce by polarized light is subjected to a magnetic field. The explanation of the phenomenon has not been clear. The results observed for mercury are shown to be in good agreement with classical electro-magnetic theory. According to Larmor's principle a magnetic field causes a precession of an electrical vibrator with angular velocity $\frac{1}{2}(e/m)(H/c)$, and to explain the present results we must hypothecate a time

of precession of about 3×10^{-7} seconds. This theory is substantially the same as that of the Zeeman effect. It is suggested that the differences observed by Wood and Ellett between the cases of mercury and of sodium are intimately connected with the differences which are known to exist in their Zeeman patterns. The results do not seem to be consistent with some of the tenets of the quantum theory.

43. Aberration of a ray of light, represented by a cone, in terms of theory of relativity (with demonstration of a geometric model). VLADIMIR KARAPETOFF, Cornell University.—An elliptical cone with two circular cross-sections is used. A generator represents the path of a particle moving at the velocity of light c. If the radii to the generator form angles δ and δ' with a reference plane, then one of the observers sees the ray at an angle δ, and another observer, moving at a relative velocity q, will see it at an angle δ'. The ellipticity of the cone depends on the angle α, where $\sin\alpha=q/c$. This leads to a novel expression for aberration, namely, $\tan\frac{1}{2}\delta/\tan\frac{1}{2}\delta'=\cos\gamma/\cos\gamma'$, where $2\gamma=90°+\alpha$ and $2\gamma'=90°-\alpha$. The observed ray is assumed to be in the XY plane and time T is used as the third dimension. The model is a generalization of the two-dimensional relativity model described by the author in Science and Invention, **11,** 442, 1923.

44. The normal and selective photo-electric effects in the alkali metals and their alloys one with another. HERBERT E. IVES and A. L. JOHNSRUD, Research Laboratories of the American Telephone and Telegraph Co. and the Western Electric Co., Inc.—The distinguishing characteristic of the selective photo-electric effect, exhibited in the liquid alloy of sodium and potassium, is an enormous enhancement of the emission under illumination at large angles of incidence for light polarized with the electric vector perpendicular to the surface. Occurring with this, in the case of sodium-potassium alloy, is a maximum in the spectral distribution of emission. Pohl and Pringsheim, finding spectral maxima of emission from rough surfaces of sodium, potassium and rubidium, concluded that those maxima proved the presence of the selective effect. Upon making mirror surfaces of potassium, by slow cooling of a pool of metal or by careful distillation on to an optical flat, the enhancement of emission at steep incidence is found to be absent; the ratio of photo-electric emissions for the two planes of polarization approximates the value two, which can be accounted for by the difference in optical absorption. Further experiments on mirrors of molten sodium, potassium, rubidium and caesium, show that the pure metals exhibit no selective effect. Of the alloys, only sodium-potassium shows selective characteristics.

45. Preliminary report on the variation of photo-electric effect with temperature. OTTO F. RITZMANN and W. R. HAM, Pennsylvania State College.—In order to test the effect of temperature on photo-electric currents at high temperatures a special tube was made consisting of a Universal Coolidge x-ray tube with an extra cathode mounted on the side toward the face of the anticathode and at right angles to its axis. The cathodes are symmetrically placed with respect to the face of the target, and either one may give an electron discharge producing x-rays which striking the other cathode produce a photo-electric current. The temperature of this second cathode is controlled and measured through its filament current, and is in general below the temperature of thermionic emission. Direct current high potential having been applied to the tube, the electron current from one cathode is measured with a milliammeter and the photo-electric current from the other is measured with a galvanometer. Since the solid angle subtended is quite large, photo-electric currents of the order of 10^{-7} ampere are obtained. It is found that on raising the temperature of the photo-electric cathode from room temperature to about 1400°C the current increases a fraction of 1 per cent apparently depending on the impressed potential difference. Results can be duplicated on either cathode.

46. Constancy of total photo-current from sodium with temperature change 20°C to −190° C. ROBERT C. BURT, California Institute of Technology.—Photo-currents from the surfaces of alkali metals have in general shown considerable changes when the surfaces were reduced to liquid air temperatures. Whether these changes have been due to a real temperature effect or to the formation of foreign surface films upon cooling in liquid air has not been determined. By the use of exceptional precautions in evacuating and by coating the inside of highly exhausted bulbs with sodium driven through the walls by electrolysis, it has been found possible to obtain a surface so pure that the photo-currents remain altogether unchanged when the bulb is dipped in liquid air. Furthermore, these surfaces show no photo-electric fatigue. This makes it possible for the first time to find the electronic work-function (long wave-length limit or critical frequency) of the alkali metals.

47. Electron emission from composite surfaces. K. H. KINGDON, Research Laboratory, General Electric Co.—(1) The electron emission from a tungsten filament, a fraction θ of whose surface is covered with thorium, can be represented by $\log_e i_\theta = \log_e (A_\theta T^2) - b_\theta T$. Langmuir (Langmuir and Kingdon, Science *57*, 58, 1923) has shown that $b_\theta = (1-\theta)b_w + \theta b_{Th}$. Since $b_w = 52600$, and $b_{Th} = 31600$ degrees, θ can be found from b_θ. The values of A_θ may be represented by the empirical formula $A_\theta = [a_w^{(1-\theta)} + a^\theta_{Th} - 1]$ where $a_w = 60$ and $a_{Th} = 6$ and $A_0 = 1$ amp./cm$^2 T^2$. (2) In a vacuum tube containing a completely formed ($\theta = 1$) thoriated tungsten filament at 1400°K, and Cs as a "getter," the electron emission is increased four-fold by the admission of a little nitrogen. The increase is about the same with the tube at 25°C or −180°C, and is not caused by ionization of the N_2. The effect is due to N adsorbed on the filament, but it does not vary rapidly with the pressure of N_2. (3) Oxygen was supplied to a hot tungsten filament at various rates. Between 1500°K and 1680°K the electron emission increased from 9×10^{-14} to 2.8×10^{-10} amp./cm^2, and was independent of the rate of supply of O_2, showing that the filament was completely covered with O. In the formula $i = AT^2 e^{-b/T}$ the constants were found to be $A = 5 \times 10^{11}$ amp./cm^2, and $b = 107{,}000$ degrees ($\phi = 9.2$ volts).

48. The application of the third law of thermodynamics to electron emission. WORTH H. RODEBUSH, University of Illinois.—Dushman attributes the failure of his equation for the electron emission from coated filaments to the absence of conditions necessary for the third law. It seems rather that the deviation is due to the neglect of the specific heat of the electron in the metal. The cases where he finds the actual emission lower than he expected are precisely the cases where the specific heat of the electron has a large positive value. The constant A can not be a universal constant, since, if it were, we should find no thermo-electric force. In the analogous case of the vapor pressure of a monatomic solid we can integrate the Debye equation and obtain $p = [\nu_0^3 (2\pi m)^{3/2}/(kT)^{\frac{1}{2}}] e - \Delta H_0/RT + 3/2$ where ν_0 is the fundamental frequency of the solid and m the mass of the atom. The question of electron emission can be approached from the standpoint of kinetic theory but the difficulty here is to assign the number of "free" electrons per unit area of surface.

49. Effective radii of gas molecules. L. L. NETTLETON, University of Wisconsin.—An investigation has been made of the *ionizing power of electrons of different velocities*. The results are expressed as the apparent radius of a gas molecule, when this radius is defined as that of the average sphere about the molecular center, through which an electron must pass to ionize the molecule. Measurements made on hydrogen, air, and mercury vapor with electrons of velocities from 100 to 2500 volts, show a regular decrease of the effective molecular radius with increasing electron velocity. By reducing the results of other experiments on ionization of air to the same basis, it is shown that for electrons ranging in velocity from 10^8 to 2.5×10^{10} cm per sec., there is

a regular decrease in the effective molecular radius of air molecules which is in general agreement with Rutherford's conclusion that the ionization should be inversely proportional to the square root of the energy of the ionizing electrons.

50. Mechanism of ionization in gases. IRVING LANGMUIR and H. A. JONES, Research Laboratory, General Electric Co.—With 30 volts or more and currents of milliamperes from a hot cathode, gases at 10 to 1000 bars are so intensely ionized that, except within a thin positive ion sheath around the cathode, the whole gas is slightly more positive than the anode (if of large area). Electrons from a filament in the axis of a cylindrical collector are projected radially with a constant velocity determined by the potential of the anode (an end-plate). The volt-ampere characteristic of the collector gives data for the free-paths of the electrons and proves that with 100-volt electrons most of the ionization is not directly caused by the collisions of electrons with atoms but the primary step is the production of a highly excited (nearly 100-volt level) atom or ion which subsequently ionizes other atoms probably photo-electrically by short-wave ultraviolet radiation. About 65 per cent of collisions of 100-volt electrons with argon atoms cause the electrons to lose all their energy in the production of the excited atoms, and about 24 per cent of the collisions cause the electrons to lose 13-volt energy (6.7-volt with mercury vapor). Eldridge's conclusions regarding ionization of mercury vapor are confirmed and extended to argon and other gases.

51. Remarks on the theory of the electric arc. PAUL S. EPSTEIN, California Institute of Technology.—It has been pointed out by K. T. Compton that the conductivity of the gas forming an electric arc can be accounted for by its thermal ionization. If this gas is really in thermal equilibrium, the positive and negative charge densities must be distributed in it according to the laws $\rho_1=\rho_0 e^{-\beta V}$ and $\rho_2=-\rho_0 e^{\beta V}$, denoting by V the electric potential, by ρ_0 a constant, and writing for short $\beta=e/kT$ (e elementary charge, k Boltzmann's constant, T absolute temperature). In the one dimensional case this leads to the equation for the potential $d^2V/dx^2=2\rho_0 \sinh \beta V$, the solution of which is $Amp(\beta V/2)=(2\beta\rho_0)^{\frac{1}{2}}x$. This formula gives roughly the right distribution of potential. It seems probable that the underlying assumption of thermal equilibrium is correct with respect to the positive ions. With respect to the electrons it is doubtful, but it is easy to modify the theory so as to cover this possibility.

52. On electrical discharges in gases with special regard to so-called dark discharges. JOHN ZELENY, Yale University.—Dark discharges between metal electrodes in gases are said to exist which have voltage-current characteristics differing from those of glow discharges. The existence of such discharges is questioned because observations with pointed electrodes show that the luminosity of glow discharges can be followed down to a current of about 1×10^{-8} amperes where the light gradually becomes imperceptible, and that there is no sudden change in the current as the voltage is reduced such as would be expected if the discharge changes its character when the light disappears. A study of the early stages of a point discharge was made when the current due to the initial ions alone could be measured on a galvanometer. When ionization by collision begins, the increase of current with voltage is quite gradual for positive discharges but is very abrupt for negative discharges. Micro-photographs taken of the luminous effects accompanying glow discharges from points in air at atmospheric pressure show the main features of these discharges. A dark space in the negative glow at atmospheric pressure corresponds to the Faraday dark space in discharges at low pressures. In helium, the Crookes dark space is visible at atmospheric pressure.

53. Mechanism of the discharge in gases. J. J. WEIGLE, Research Laboratory, Westinghouse Elec. and Mfg. Co.—Calculations of the energy acquired by an ion along one mean free path show that when the distance between the electrodes is great in comparison with the mean free path, the energy necessary to maintain the discharg

is smaller than the energy required to ionize a molecule. The Clausius law of repartition of free paths must come into consideration and in this way Towsend obtained an equation for α, the number of ionizing collisions in 1 cm. The experimental values of the probability of an electron ionizing a molecule show that it is a function only of the total number of collisions, and not separately of the pressure of the gas or the distance between the electrodes. This result is another way of formulating the Paschen law, but the experimental curve shows a completely different shape than the curve calculated from $\alpha-\beta$, $e^{(\alpha-\beta)a}=0$, the Towsend expression of the Paschen law. A theoretical explanation of this fact will be given in a later paper.

54. Diffusion of ions in neon tubes. T. E. FOULKE and W. H. MCCURDY, Edison Lamp Works, Harrison, New Jersey (Introduced by Saul Dushman).—The discharge was studied by ionizing the gas at the cathode by means of an auxiliary electrode. Electrons were then drawn from this discharge through the tube to the anode. The volt-ampere characteristics of the anode circuit were determined as a function of auxiliary gap current and voltage, tube diameter and length, and gas pressure. The following results were obtained: (1) Below the first ionizing potential the anode current depends on the auxiliary gap current, pressure, and tube diameter, but little on the voltage. The currents as a rule exceed the space current obtainable in a good vacuum. (2) At multiples of the ionization potential the anode currents increase about tenfold, finally reaching an upper limit. The conclusions drawn are as follows: (1) The initial current is due to a diffusion of ionized gas from the cathode region. (2) The current that is conducted through the tube is generated in the cathode region and is essentially a pure electron current. (3) The effect of the ionization in the positive column is to neutralize the space charge of the electron current. (4) The excess ions formed recombine. (5) The Faraday dark space is found to be the distance in which the electrons gain ionizing velocity.

55. Exponential rise of discharge currents in neon. T. E. FOULKE, Edison Lamp Works, Harrison, New Jersey (Introduced by Saul Dushman).—Assuming inelastic collisions, Townsend has derived a relation between the maximum number of electrons N produced by collision from N_0 electrons originating at the cathode, of the form $N=N_0 e^{V/V_i e}$, where V is the anode voltage and V_i denotes the ionization potential. It has been shown by Hertz, Compton and others, that in monatomic gases, the collisions are elastic below certain critical potentials. In the case of neon this potential coincides with that required for ionization (21.7 volts). The experimental results in neon (with either a hot cathode or photo-electric source of electrons) can be expressed by the relation $N=N_0 e^{V/V_i-1}$. This equation may be derived on the basis of the following assumptions: (1) That the ionization in neon is due to single impact at 21.7 volts, (2) that the collisions are elastic up to this potential, and (3) that the ionization per electron is X/V_i ions per cm of path, where X is the potential gradient. This relation is valid until the space charge, due to positive ions, causes a redistribution of the field, and for pressures great enough to insure at least V/V_i ionizing collisions between the electrodes. According to the work of Compton and Holst, it would be expected that the relation $N=N_0 e^{V/V_i}$ holds for this case. The experimental data in neon, however, are not in agreement with this latter relation. Further work is being carried out on other gases.

56. Excited atoms in the striated glow discharge in mercury vapor. W. H. MCCURDY, LOUIS A. TURNER and K. T. COMPTON, Princeton University.—The first author has found that striations are possible only in the presence of slight impurities, that they occur at 5 volt intervals and that the current increases as impurities are removed. The interpretation suggested is that ionization in the striations is cumulative, depending on the existence of excited atoms, and that the action of impurities is to reduce the

concentration of excited atoms and prevent their diffusion into the dark spaces between striations. It is shown that mobility and space charge considerations explain the existence of striations only if diffusion of excited atoms is suppressed. To test this hypothesis, the spectrum of light from a separate mercury arc was photographed before and after passing through various regions in the positive column. Regions of glow were found to absorb all lines ending with $2p_{1,2,3}$ states, while dark regions did not thus absorb. The absorption became more prominent as the impurity was pumped out, being strongest in the uniform positive column. Conclusions: $2p_{1,2,3}$ excited atoms exist in large concentration in the striations but not in the dark spaces; impurities reduce these concentrations; the metastable states $2p_{1,3}$ are relatively most prominent; absorption involving inter-system transitions is less probable than that in one system.

57. Metastable states in low voltage mercury arcs. MILTON MARSHALL, University of Chicago.—Characteristic curves of alternating current arcs in mercury vapor were observed by means of a Braun tube oscillograph and showed analogous phenomena to those observed by Kannenstine in helium. With low frequency the arc struck between 12 and 20 volts depending on the pressure. By increasing the frequency a critical frequency could be found above which the arc struck at an applied voltage of about 3 volts. This frequency was constant over a considerable range of pressure but increased at low pressures. With various tubes and different degrees of purification this critical frequency ranged from 40 to 12 cycles. This time at which a low voltage will restrike the arc after it has been extinguished was verified by means of a commutator which short circuited the arc for 0.046 seconds and then applied the low striking voltage. The actual voltages required to cause ionization in the metastable products formed in the arc were obtained more exactly by intermittent arcs. Assuming 10.4 volts as the ionizing voltage for reference, the lowest ionizing voltage in the intermittent arc was approximately 5.0 volts. A second ionizing voltage was observed which was 0.8 volt higher. These figures agree with what would be expected for ionization of the $2p_1$ and $2p_3$ states, which from spectroscopic considerations should be metastable.

58. The energy of high velocity electrons. MARSH W. WHITE and W. R. HAM, Pennsylvania State College.—A determination of the heat generated by high velocity electrons at the molybdenum anode of an oil immersed and oil cooled Coolidge x-ray tube was made by noting the temperature rise of the oil. The current and voltage furnished to the tube by a high tension direct current source was kept constant and continuously measured by potentiometers. Such measurements indicate that the total energy of the electron stream converted into heat during a one hour period remains constant within about 0.1 per cent when the voltage is raised from 10 kv to 23 kv and the current proportionately reduced; furthermore the rates of heating are equal. The same potentiometers measured the current and voltage supplied to a heating coil immersed in the oil. The heat developed by this "low potential" source was the same, within about 0.1 per cent as that developed from the "high potential" electron stream for equal powers and times. Other data indicate that no heat is generated at the cathode. Hence, if the energy due to x-radiation is included, the rate at which heat is generated by the electron stream in an x-ray tube is given within 0.1 per cent by the product of current and voltage.

59. The deflection of an electron beam by an alternating electric field externally applied. L. T. JONES, University of California.—A constant electrostatic deflection of a cathode beam is obtained only by an internally applied electric field. A varying external electric field produces a varying deflection, the deflection being a maximum at the moment of greatest rate of change of the electric field. This may be peculiar to the single frequency thus far used (60 cycles a.c.). Ebert failed to obtain this 90° phase difference and attributed the deflection to an "effect of the glass" of the tube. Addi-

tional glass placed in the field alters neither phase nor magnitude of the deflection. It is difficult to reconcile J. J. Thomson's compensating layer of electrons, high electron mobility and a deflection, particularly a deflection of 90° phase, with the deflecting field. The phase and deflection are both readily explained on the basis of a magnetic effect of the varying electric field. The magnitude of the deflection is not readily explained, but is apparently a function of the intensity of the electron beam.

60. The mobility of actinium B in air. HENRY A. ERIKSON, University of Minnesota.—Air is drawn with a velocity of 2000 cm per sec. between two parallel plates, 4 cm apart, between which there is an electric field. The actinium B enters in a thin sheet of air at and parallel to one of the plates, and being positively charged, it is forced by the field to the opposite plate where it adheres to the surface at a point whose distance down stream depends upon its mobility in air, the air velocity and the potential gradient. The plate with the active deposit is removed, covered with another plate having a 5 mm slit at right angles to the plate, and is placed inside of an ionization chamber. The current due to the active deposit at the different down stream distances on the plate is then measured by means of a quadrant electrometer. It is found that the curve showing the relation between the current as ordinate and the down stream distance as abscissa has two maxima, one of which corresponds to a mobility in air of 3.15 cm/sec/volt/cm and the other to a mobility of 1.20. The interpretation of these results is not clear, but it is believed that at least the greater mobility value (3.15) is due to atomic actinium B. It is significant that the slowest of the above ions has a mobility of the same order as the final positive air ion (1.36), although its mass is much greater, and the other, though also of a much greater mass, has a mobility greater than either the initial positive or negative air ions (1.87). This signifies that, aside from the charge, it is the ionic volume rather than the ionic mass which determines the mobility.

61. A method for studying the ionization of the less volatile metals. K. H. KINGDON, Research Laboratories, General Electric Co.—When an atom strikes a hot surface whose electron emission work function ϕ is greater than the ionization potential V of the atom, an electron is taken from the atom by the surface, and the resulting positive ion evaporates. A hot tungsten filament will ionize any atom for which V is less than 4.5 volts. The method may be extended by the use of a tungsten filament covered with a monatomic layer of oxygen ($\phi=9.2$ volts). In this way ions of Cu ($V=7.69$), Bi ($V=8$), Ca ($V=6.1$) have been obtained, whereas Hg ($V=10.4$) does not show the effect. A little of the metal is vaporized on to the oxygen-covered surface. The latter is then suddenly heated to 1400°K and the evaporated ions observed by the kick of a ballistic galvanometer. Or the metal may be allowed to strike the hot filament at a steady rate, and the steady ion current measured. By evaporation of some of the oxygen, ϕ may be reduced to any value between 9.2 and 4.5, and by studying ion generation at these partially covered surfaces estimates of the ionization potentials of the metals can be made. (Cf. Kingdon and Langmuir, Phys. Rev. **21,** 380, 1923.)

62. The source of the penetrating radiation found in the earth's atmosphere. RUSSELL M. OTIS and R. A. MILLIKAN, California Institute of Technology.—Assuming, following Kolhörster's 1923 conclusions, a penetrating radiation of cosmic origin which produces 2 ions/cc/sec. at sea level and has an absorption coefficient per cm in water of 2.5×10^{-3}, we find that this radiation would produce 9 ions/cc/sec. on top of Pike's Peak (14100 ft). Inside our completely enclosing lead shield, 5 cm thick, it should produce 7.8 ions/cc/sec. The ionization in our apparatus contributed by the walls and the lead shield was found to be at least 7 ions/cc/sec., so that if there were no local radiation on Pike's Peak, the lowest obtainable value of the ionization in our shielded vessel should have been 14.8 ions/cc/sec. We observed as low as 11. We conclude, therefore, that there exists no such penetrating radiation as we have assumed. Second,

we found as a result of a snow-storm on the mountain as large a percentage change (about 10 per cent) in the ionization inside our 5 cm lead shield as outside it. We interpret this result also as meaning that the whole of the penetrating radiation is of local origin. How such quantities of radioactive material get into the upper air is as yet unknown.

63. Results of preliminary earth-current measurements at the Carnegie Institution's Magnetic Observatory near Watheroo, Western Australia. O. H. GISH, Department of Terrestrial Magnetism, Carnegie Institution of Washington.—The first continuous records of earth currents in the Southern Hemisphere were obtained in October 1923 on the recently constructed experimental lines at the Watheroo Magnetic Observatory. The method of measurement employed there is described in Terr. Mag. **28,** 89-108, Sept. 1923. The chief novel features are: (1) The use of five earthed points instead of the usual three, (2) provision for comparing the relative efficacy of aerial and subterranean connecting lines, and (3) the use of a multiple-point recording potentiometer. The preliminary results obtained in November and December 1923 seem to show that the method employed is very satisfactory and has some distinctive advantages. Both gradient components show a pronounced diurnal variation. The south-north, taken positive when directed northward, has a principal maximum at about 7 a. m., a principal minimum near noon, a secondary maximum at about 5 p. m., and a secondary minimum near midnight, results which are in qualitative agreement with the data from Berlin and Ebro. The east-west component, taken positive when directed westward, is however simpler in form, showing only a single period, with maximum at 9 or 10 p. m. and a minimum near 11 a. m.

64. Note on the theory of the single fiber electroscope. W. F. G. SWANN, University of Chicago.—If k is the mechanical restoring force per unit displacement of the fiber, the actual restoring force per unit displacement may readily be shown to be $k-CX^2$, where C is the capacity of the fiber and X the field between the plates. The deflecting force due to a change of potential δV in the fiber is $CX\delta V$, so that the sensitivity s is $s=CX/(k-CX^2)$. If k is less than CX^2 the instrument is unstable, and the fiber flies to either one plate or the other. The sensitivity becomes very large if $k-CX^2$ is small; and, in obtaining high sensitivity from the instrument, this condition is usually satisfied, even though the fact may not be realized. It is a bad condition since it results in large variations in s for small variations in either k or X. If we should desire to restrict ourselves to the case $k-CX^2=\frac{1}{2}k$, so that we draw upon the term CX^2 to the extent of no more than doubling the sensitivity which we should obtain in its absence, s reduces to the very simple expression $s=1/X$ which, under a magnification of 100 gives a deflection of 1000 mm per volt for a field of one volt per cm between the plates. High sensitivity consistent with great constancy *necessitates a small field* between the plates, and correspondingly small value of k. An instrument meeting the required conditions is described.

65. The Ampere trough experiment and its explanation by the usual electromagnetic laws. F. W. GROVER, J. P. DAS and J. TURNBULL, Union College.—In Jour. Franklin Inst. p. 559, Nov. 1921, Carl Hering describes a modification of the classical Ampere trough experiment for whose explanation he believes the usual electromagnetic laws inadequate. The present paper gives detailed experimental and mathematical analysis of this circuit. The circuit is a wire rectangle $ABCD$, 70 cm long, 25 cm wide, interrupted at the center of one long side CD by troughs of mercury, of rectangular cross section, 4 cm by 1 cm deep, perpendicular to CD and spaced 5 cm between centers. With the bridge close to CD on either side, there is no perceptible force. With the bridge inside the rectangle and 2 cm to 20 cm from CD, the force is away from CD. With the bridge inside the rectangle and more than 20 cm from CD, the force is *toward* CD.

With the bridge outside the rectangle and more than 2 cm from *CD*, the force is *away* from *CD*. If the length of conductor in the circuit be increased by movement of the bridge, an increase of inductance is possible even with a decrease of the area enclosed by the circuit. Calculation shows a maximum or minimum of inductance in regions where the direction of force changes. The bridge always moves so as to *increase* the inductance. Inductance measurements check the calculated values. Furthermore, analysis of the forces between the bridge and the other elements of the circuit by the usual laws explains the observed movements of the bridge. Recently published results of Morecroft, A.I.E.E., p. 1191, Nov. 1923, confirm these conclusions.

66. A method of measurement of cyclic changes of resistance. F. WENNER and F. M. SOULE, Bureau of Standards.—The method is a modification of that used by Schuster more than 50 years ago in his investigation of Ohm's law and by Perkins recently in his first investigation of the effect of charge upon conductivity of metallic conductors. In both of these investigations erroneous conclusions were drawn because of a similar error in the measurements. The modification made is such that only a negligible part of the test current passes through the galvanometer. This results in a very marked increase in both the sensitivity and in the reliability of the results obtained. Under favorable conditions cyclic changes in resistance can be detected with certainty when these amount to but 1 part in 10^8 of the resistance of the conductor in which they occur. This reliability may be obtained for pure metal conductors using a moving coil galvanometer and without control of the temperature. The method is suitable for frequencies from about 1 cycle per second upward to 10000 cycles per second or even higher. However, it is applicable only in those cases in which an alternating test current can be definitely synchronized with the cyclic changes in resistance.

67. The variation in the resistance of carbon and graphite with temperature. BRADFORD NOYES, JR., Cornell University.—(1) *Variation with temperature.* The resistance of *carbon* was found to decrease linearly with temperature. Several different specimens, made from braided silk, were observed from −190° to 2000°C. *Metallized filaments* showed a rapid decrease in resistance to about 400°C, when the coefficient changed. The resistance at 2000°C was found to be about twice the room temperature resistance. *Graphite*, made by the Acheson Company and purified by heating, behaved similarly to the metallized filament. A minimum in its resistance occurred about 600°C, the resistance above this point seeming almost a linear function of temperature. It was found that these experimental results do not fit either the law proposed by Bidwell, or that proposed by Waterman. (2) *Variation with air pressure.* Graphite, in the presence of air at about ¼ atmospheric pressure, was found to have resistance about 4 per cent lower at 500° than the same specimen had in a vacuum. This effect decreased with temperature, the resistance at room temperature being the same whether the specimen was in the air or vacuum. (3) At about 2200°C the length of carbon specimen was observed to increase, bending the specimen. This *increase in length* became permanent, and the bend remained even when the specimen was cooled.

68. An alternating current bridge for the measurement of the small phase angle of a high resistance. IRVING WOLFF, Cornell University.—An alternating current bridge has been developed for measuring capacities of the order of a microfarad to within a few percent when they are in series with 100,000 ohms or less. The action of the bridge depends on the addition of a fourth low resistance arm in addition to the usual Wagner arm. This makes possible a new method of adjustment of the Wagner arm which with the characteristics of the vacuum tube as detector allows the elimination of distributed capacity and inductance and earth capacity effects in the adjustable arms of the bridge and of earth capacity effects in the object to be measured. Tests made on known resistances and capacities have given satisfactory results.

69. Electrical resistance and thermo-electric power as a function of temperature. A. T. WATERMAN, Yale University.—In the writer's derivation (Phys. Rev. **22,** 3, 1923) of an expression for the free electron concentration within a conductor, the effect of the specific heat of electricity on the temperature variation of the ordinary electron evaporation constant was neglected in the usual manner. The inclusion of the specific heat term now improves the expression for the temperature variation of resistance already given, and also leads to a satisfactory equation for the thermo-electric power as a function of temperature. Thus taking the electron evaporation constant as $\psi=\psi_0+3/2kT-\int\epsilon\sigma dT$, and assuming $\sigma=\sigma_0 T$, the specific resistance becomes (1) $\rho=CT^a e^{b/T-cT}$ where (for unit valence) $a=1.25$, $b=(\phi_0-\psi_0)/2k$, $c=\epsilon\sigma_0/4k$. The thermo-electric power is (2) $Q=A+B/T+CT$, where $B=-(k/\epsilon)(b_2-b_1)$, and $C=(k/\epsilon)(c_2-c_1)$. For pure metals at ordinary temperatures the term B/T is small, and thus Eq. (2) very closely approximates the familiar linear form. The application of (1) and (2) to Bidwell's data (Phys. Rev. **23,** 3, 1924) for the alkali metals (where unit valence is essential) gives fair agreement both for thermo-electric power and temperature variation of resistance, in the solid state.

70. The significance of formulas for the inductance of a portion of a circuit. FREDERICK W. GROVER, Union College.—Since currents flow in closed circuits only, the concept of the inductance of an element of circuit can have practical significance only when defined with reference to its contribution toward the total inductance of the circuit. Thus self and mutual inductances of the elements of circuit should be defined so that the total inductance of the circuit can be obtained by summing contributions of the elements to the total. This agrees with common practice for a circuit composed of a number of mutually reactive coils joined in series. There is no essential difference between the mutual inductance of two isolated coils and that of two isolated straight wires. Accordingly, the mutual inductance of two straight wires AB and CD is defined including only that portion of the infinite number of flux linkages (unit current in AB) included between semi-infinite planes perpendicular to AB through the ends of CD. Flux linkages in question between CD and infinity are in the direction away from AB. Existing formulas for mutual inductance of wires agree with this definition. The objection urged against the use of the Biot-Savart law for deriving such formulas is rendered invalid by thus defining the inductance of an element with regard to the whole circuit.

71. An improved method for determining the dielectric constant of gases. C. T. ZAHN, Princeton University.—A modification of the use of high frequency oscillations for determining dielectric constants has been developed. Two generators produce in a detector-amplifier a heterodyne note which is adjusted by beats with a tuning fork. One generator is fixed; the other contains two capacities, C and K in series. C is the gas condenser; K, a large capacity with a small variable part. A small change in C, due to the gas, requires for compensation a large change in K given by $dK/dC=-(K/C)^2$, which can be made as large as desired. This is a null method and it depends in no way upon either the electron tube constants or the distributed capacity of coils unless these change erratically. The limit of accuracy depends then on the calibration of the condenser system and the steadiness of the circuits. It was found possible to detect with facility a dielectric constant given by $\epsilon-1=10^{-6}$, which corresponds to about one beat per second. Measurements were made on air, nitrogen, oxygen, and hydrogen.

72. The electric moment of gaseous HCl and HBr molecules. K. T. COMPTON and C. T. ZAHN, Princeton University.—By a method described in the preceding paper by one of the authors, measurements have been made of the dielectric constant of gaseous HCl and HBr throughout a temperature range of about 400°C beginning just above the liquefaction point. In order to prevent chemical action the condenser used was made of an alloy of gold with small quantities of platinum and palladium and

mounted in a Pyrex tube. Temperatures were measured to at least an accuracy of one-tenth degree by a platinum resistance thermometer wound around the condenser cylinder. The data obey accurately the Debye equation $(\epsilon-1)/(\epsilon+2)\rho=A+B/T$, based on the existence of fixed moments in the molecule. For HBr the moment is .7881 $\times 10^{-18}$ c.g.s.u. for HCl, 1.03×10^{-18} c.g.s.u. The latter value comes out about one-half the value given recently by Weigt and Falkenhagen and is about one-sixth the limiting value given for it by infra-red absorption data. It is therefore impossible to decide between Debye's classical theory and Pauli's quantum theory of dielectric constant by comparison of these experimental results with data calculated from infra-red absorption.

73. Potentials and Hertzian vectors for certain electromagnetic fields. H. BATEMAN and P. EHRENFEST, California Institute of Technology.—The field in which electric dipoles break up at the origin and radiate their constituents in opposite directions with velocity c, may be derived from a simple Hertzian vector involving the gradient of the logarithm of the ratio of $r+z$ to $r-z$. By operating on the field vectors with $\partial/\partial z+(1/c)\partial/\partial t$ the singularities radiated in one direction are eliminated. An operation $(1/c^2)\partial^2/\partial t^2-\partial^2/\partial z^2$, or the equivalent operation $\partial^2/\partial^2 x+\partial^2/\partial y^2$, eliminates both sets of radiated singularities and leaves the field of a fluctuating Hertzian dipole. The result of the last operation may be interpreted in terms of radiated pairs of quadrupoles and leads to a surprising conclusion.

74. Complete electromagnetic equations and a single system of units. GEORGE A. CAMPBELL, American Telephone and Telegraph Co.—The fundamental curl, wave, and activity equations are written: curl $H=GE+C\dot{E}=(\Gamma/K)E$;

$$-\text{curl } E=RH+L\dot{H}=(\Gamma K)H;\quad \Delta E=CL\ddot{E}+(RC+LG)\dot{E}+GRE=\Gamma^2E;$$

$$-\text{div } (E\times H)=d(\tfrac{1}{2}CE^2+\tfrac{1}{2}LH^2)/dt+GE^2+RH^2=(\Gamma/K)E^2+(\Gamma K)H^2;$$

$$\Gamma=[(R+ipL)(G+ipC)]^{\frac{1}{2}}=\text{propagation constant};$$

$$K=[(R+ipL)/(G+ipC)]^{\frac{1}{2}}=\text{iterative impedance};$$

where G, C, R and L are the conductance, capacity, hysteresis and inductance of a unit cube of the medium, which is the simplest unit into which the medium may be resolved. The discussion of any medium is thus made uniform with the ordinary discussion of any network since both are based on the values of G, C, R and L for the component units of the medium or network. It is urged that in all theoretical discussions of both media and networks the same units be employed as in actual physical measurements. The international metric and electric units considered as a meter-second-watt-ohm system are adapted for this purpose; the great numerical range required of a single system of basic units is conveniently obtained by using mega and micro numerical multiples (supplemented in special cases by kilo and milli multiples).

75. New researches on the magnetization of ferromagnetic substances by rotation and the nature of the elementary magnet. S. J. BARNETT and L. J. H. BARNETT, Carnegie Institution of Washington and California Institute of Technology.—In the last two years we have studied many rotors of soft iron, cold-rolled and annealed steel, nickel, cobalt, iron-cobalt, iron-nickel, cobalt-nickel, and Heusler's alloy. Great improvements have been made in the driving mechanism, in the compensating systems, in the construction of the rotors and rotor bearings, in the mounting of the magnetometer and methods of adjusting and testing it, and in the elimination of errors generally. The mean results do not differ greatly from the best of those we have published before; but the new results are more certain, precise, and extensive. The mean specific magnetic intensity of rotation λ (equal to the ratio of the angular momentum of the elementary magnet to its magnetic moment on the simplest classical hypothesis) is found to be close to $1.06\times m/e$. The average error for the individual rotors is about 1.2 per cent, and the average departure of λ for the individual rotors from the general mean is about 2.2 per cent. The above value is nearly a mean between the values obtained in the best

two determinations by the converse effect (Beck, Chattock and Bates) in iron and nickel. Classical theory requires $\lambda = 2m/e$; recent developments in quantum theory favor $\lambda = m/e$, but in comparatively simple cases.

76. Mechanical control of magnetization and of hysteresis in permalloy. O. E. BUCKLEY, Research Laboratories of the American Telephone and Telegraph Co. and Western Electric Co., Inc., New York.—*Nickel-iron alloys* containing 65 and 84 per cent of nickel show opposite effects of tension on magnetization. An alloy containing 81 per cent of nickel is nearly indifferent to tension. Incomplete annealing may completely mask the characteristic differences. Whenever magnetization is favored by tension the *hysteresis loss* is diminished. In an especially well-annealed alloy containing 78.5 per cent of nickel both effects are enormous, hysteresis in particular being reducible to about one hundredth of its amount in the best silicon steel. Residual hysteresis is so little that it is natural to regard it as evidence of slight inhomogeneity in the specimen rather than as an essential characteristic of the magnetizing process. The practically complete saturation of properly stressed wires in very weak magnetic fields taken in connection with x-ray photographs makes it very improbable that the equilibrium positions of the elementary magnets are connected in any way with crystal structures, except as the latter may introduce or modify stresses within the specimen.

77. A contribution to the theory of ferromagnetism. L. W. MCKEEHAN, Research Laboratories of the American Telephone and Telegraph Co. and Western Electric Co., Inc., New York.—The usual theories of ferromagnetism are inconsistent with modern views of atomic processes and are incapable of accounting for the magnetic properties of permalloy. A purely atomic quantum theory, as is pointed out, does not account for the magnetic hardness and hysteresis of ordinary materials. This defect is remedied by considering that the magnetization must proceed discontinuously in space as well as in time. This leads to the conclusion that atomic magnetostrictions, or rather the strains produced thereby, are the chief source of magnetic hardness in all cases. The abnormality of permalloy is explained as due to the fact that the atomic magnetostrictions in iron and nickel are of opposite types, so that in an alloy having the right proportion and distribution of the two elements, magnetostrictive strains due to either element are relieved by the magnetization of the other. The theory offers a reasonable explanation of the dependence of magnetic hardness upon mechanical hardness, and for the efficiency of annealing and quenching in altering magnetic quality.

78. On the temperature coefficient of frequency of quartz resonators. W. F. POWERS, Wesleyan University.—Provisional data obtained with crystals of 91 kilocycles frequency indicate that from 20°C to 110°C the frequency decreases by 0.0005 per cent of its value at 20°C for an increase in temperature of 1°C. Temperature coefficient of frequency is thus of the same order of magnitude as the thermal coefficient of linear expansion. A quartz slab 3 cm × 0.5 cm × 0.15 cm, approximately, is mounted between two brass plates 0.05 cm thick at a separation of 0.6 cm on a "Formica" base; clearance between brass plates and crystal is large enough to make the expansion effect of the crystal's mounting negligible. This system is heated in a furnace and connected to a non-regenerative tube circuit. To this is loosely coupled a generating circuit which is brought into resonance with the crystal at its different temperatures by the "key-tapping" method described by Prof. Cady (Proc. I. R. E. **10**, 109, 1922). A second crystal at constant temperature is used to determine variations in frequency of the generating circuit. The percentage probable error of a single comparison of frequency of the generating circuit with that of the crystal at constant temperature determined from 10 trials in quick succession is somewhat better than 0.001 per cent.

79. A method of producing a square wave of radio frequency. J. L. BOWMAN, University of Chicago (introduced by W. F. G. Swann).—A square wave of high frequency

is necessary in the measurement of electronic mobilities. The oscillations of a tube circuit A are rectified by a tube B and applied to the grid of a tube C in such a way that the grid is equal in potential to its filament during half the cycle and negative thereto during the other half. As a result, the potential difference between the ends of a resistance in the plate circuit of C suffers sudden increases and decreases between zero and a maximum value, remaining sensibly constant between these changes, thus giving rise to a square wave. The sharpness of the changes between zero and the maximum increases with increase of the amplitude of the voltage applied to the grid of tube B. This must not be too great for the safety of the tube. However, by suitably connecting the grid of tube B to tube A, through a battery, it is arranged that, after B has attained a potential of about 15 volts, the positive current leaving it becomes sufficiently great to insure that the upper half of its voltage-time curve is greatly flattened, thus avoiding a dangerously high voltage.

80. A preliminary report on the breath expulsion in singing with relation to pitch and intensity. DOUGLAS STANLEY and H. H. SHELDON, New York University.—The voices of various singers have been analyzed from the physiological and musical viewpoints with special reference to proper and improper tone phonations. These voices were then analyzed by physical means, regarding the voice merely as a sound-producing instrument. The physical analysis was made by a study of curves showing breath expulsion against intensity and breath expulsion against pitch. Over the head of the singer was strapped an air-tight mask in which was mounted a large tube opening into a spirometer and a telephone transmitter. This transmitter operated an oscillograph through a specially constructed three-stage amplifier. By these means intensity and breath expulsion were measured.

81. Some characteristics of a hot wire phonometer. ORIN TUGMAN, Riverbank Laboratories.—The resistance of a platinum wire mounted in a horizontal slit over a brass tube and heated by a current of electricity, is changed by a sound wave passing through the slit. In this experiment the change of resistance was measured by a potentiometer. The relation between intensity of sound and change of resistance was determined by mounting a calibrated telephone receiver over the apparatus and operating the receiver by a filtered current from a vacuum tube oscillator. For any given frequency a linear relation was found between the change of resistance and the square of the amplitude of the receiver diaphragm.

82. Sound intensity attenuation measurements on voice tubes. P. P. QUAYLE and E. A. ECKHARDT, Bureau of Standards.—The dissipation of sound energy along a voice tube transmission line is mathematically analogous to the dissipation of light in an absorbing medium and is therefore expressible by the equation $dI/dx = -\alpha I$. Measurements of the ratio of output to input intensities for voice tube lines which were progressively changed in length showed α to be constant within the errors of measurement and it may therefore be concluded that the equation adequately represents the intensity attenuation. The absorption constant α has been found to be greater for the higher pitches of the voice range than for the lower. Values for α have been determined for typical types of tubing. Design of a voice tube installation to give a predetermined intensity attenuation is therefore made possible. Difficulties due to resonant response of the tubing were minimized by using a sound source the frequency of which varied cyclically over a band of frequencies. The source of sound was a magnetophone supplied from an electron tube oscillator. By driving the rotor of an air condenser by means of a motor the oscillator frequency and hence the sound frequency was varied cyclically. This work was done in cooperation with the Navy Department.

83. Measurement of vibrations in building structures. F. R. WATSON, University of Illinois.—By means of a portable seismometer, patterned after the model described

by P. G. Nutting (A Portable Seismometer, Jour. Opt. Soc. of America, **6**, 629, 1922), vibrations of floors, table tops and other structures were magnified and photographed. The actual vibration of the structure was measured by noting with a microscope the motion of the seismometer mass. By these experiments, an analysis may be made that gives the frequency and amplitude of the component motions. It is also possible to measure the amplitudes of motion of partitions in comparison with the intensities of the sound given out.

84. Position finding in hydrography by a radio acoustic method. M. KEISER and E. A. ECKHARDT, Bureau of Standards.—The distance between two points is determinable by starting sound and radio signals at one and observing the time interval between their arrivals at the other. No appreciable error results in assuming the arrival and departure times of the radio signal to coincide. The distance is determined by multiplying the observed time by the sound velocity. A ship making depth soundings to be used in the preparation of hydrographic maps uses auxiliary shore stations. The ship is equipped for recording radio signals on a chronograph drum and for transmitting sound signals. At each shore station a hydrophone receives the sound signal and auxiliary apparatus provides for the automatic transmission of radio signals as a result thereof. The ship records the instant of firing a bomb as well as those at which the radio signals from the shore stations arrive. The travel times of the sound through the water from ship to each shore station are read from the chronograph chart. They are corrected for the lags which are currently determined. The combination of the computed distances gives the position of the ship on the chart. The operations of the ship are therefore independent of visibility. This work was done in cooperation with the U. S. Coast and Geodetic Survey.

85. The vapor pressure constant for silver. ROBERT J. PIERSOL, Research Laboratory, Westinghouse Elec. and Mfg. Co.—At higher temperatures, light reflection from polished silver surfaces changes rapidly from specular to diffuse due to evaporation. The rate of evaporation is determined at different temperatures by the loss in weight of silver filaments, 0.0051 cm in diameter and 10 cm in length. The vapor pressure of silver may be calculated using the kinetic relation, $m=p(M/2\pi RT)^{\frac{1}{2}}$. This data may be used to establish the constant for silver in the Hildebrand vapor pressure curve, $\log p=-3140\ C/T+7.85+\log C$, where C is the constant for silver. Calculation shows C to be 3.95. Von Wartenberg, using a dynamic method, gives the value of C as 4.30. On the other hand, Greenwood, observing the boiling points of silver at pressures of 0.14, 0.35 and 1.0 atmosphere, obtained results in agreement with 3.95 as the silver constant.

86. An electric furnace giving very uniform temperatures. WALTER P. WHITE, Geophysical Laboratory.—In precision work involving electric furnaces uniformity of furnace temperature in the majority of cases offers by far the most serious problem in the whole experiment. The furnace here described was of favorable dimensions, 2.7 cm wide and 25 cm long. Heaters in or across the ends, however, were not desirable. Two familiar devices were used: (1) The furnace tube which carried the winding was of silver 3 mm thick; (2) the end coils were separately regulated. Three features were new: (3) Alundum tubes 7 cm long continued the central silver tubes, affording thermal insulation at the ends. (4) The regulated end coils were wound on these tubes, thus diminishing the cooling effect of the ends. (5) The outer 6 cm at each end of the silver tube were occupied by 4 cup-shaped silver partitions in order to bring the wall temperature across the ends. By suitable regulation of the end heating coils the uniformity over the middle 14 cm was brought to 0.1° at 600°, or 0.2 per mille of the furnace temperature. When no current at all was used in the end coils, the maximum temperature difference within the 14 cm space was 7 per mille. It was about the same when the end coils were heated and no heat whatever was generated along the silver tube itself.

87. The molecular wedge theory of emulsions. WILLIAM D. HARKINS and ERNEST B. KEITH, University of Chicago.—An earlier paper (1917) indicated the shape of the soap molecules in the interface between water and oil to be important in the determination of the sizes of the drops in an emulsion, and whether the drops shall be of oil or of water. Finkle, Draper, and Hildebrand have found that the sizes of drops in emulsions produced by sodium, potassium, and caesium palmitate, are in accord with the theory. We find: (1) The curve for the distribution of the diameters of oil drops in an emulsion is similar to the Maxwell distribution curve for velocities. (2) The most probable size was found to be 4.7, 3.9, 2.9, and 1.95 microns diameter for lithium, sodium, potassium, and caesium oleates, respectively, when octane was emulsified; slightly more than twice these diameters with a heavy paraffin oil; and about half with benzol or mesitylene. (3) Bases, salts, and oleic acid greatly decrease the size of the drops. (4) The peaks of the distribution curves lie on an equilateral hyperbola. (5) The drops are about 0.060 volt negative with respect to the 0.1 molar aqueous soap solution, but this is decreased to 0.045 volt by 0.1 molar base. (6) Oleic acid inverted heptane is emulsified by sodium oleate to a water in oil emulsion.

88. Effect of humidity upon photographic speed. P. V. WELLS and J. F. HEINEKEN, E. I. du Pont de Nemours and Co., Parlin, N. J.—It is of interest in the theory of the photographic process that the speed of photographic materials depends upon their humidity during exposure. Although few quantitative data have been published it is well known that the speed is usually greater in dry atmospheres; but we have failed to find any references in the literature to the fact that with some types of photographic material the speed falls again in extremely dry atmospheres. We have investigated the humidity effect upon commercial positive and negative motion picture film. Thirty-six tests were made on cine-positives at each of the humidities 0, .20, .40, and .80, with an average deviation in a single test of less than 5 per cent in H and D speed. The effect varies with the type of film, but on the average the speed increases 7 per cent from .80 to .40 humidity, increases 7 per cent from .40 to .20 humidity, but decreases 4 per cent from .20 to 0 humidity. Twenty tests were made on four types of commercial cine-negatives at each of the above four humidities. Here again the effect varies with the type of film, but the average speed increases 7 per cent from .80 to .40 humidity, increases 9 per cent from .40 to .20 humidity, and decreases 16 per cent from .20 to 0 humidity. Most motion picture films, therefore, possess the remarkable characteristic of a maximum speed at somewhere about .20 humidity.

89. The peculiar behavior of quartz under high compression tests. S. N. PETRENKO, Bureau of Standards.—Samples of fused quartz were tested in compression, bending and tension, the elastic properties being determined with an optical extensometer. (1). *Compression test.* The compressive strength of fused quartz specimens about 0.55 in. in diameter and 2 in. long was found to depend greatly upon the medium used to distribute the pressure uniformly over the ends. The highest value, 191,000 lb/in.^{2} was obtained with a specimen having the ends covered with grease; paraffin, soft lead and paper gave much lower values. The failure was of a violent nature, the specimens disintegrating into fine powder. A modulus of elasticity of about 14,200,000 lb/in.^{2} was obtained. (2) *Transverse test.* The modulus of rupture was about 10,000 lb/in.^{2} and the modulus of elasticity about 12,000,000 lb/in.^{2}. The failure resembled that of hard steel, the specimen being always broken into three parts. (3) The results of tensile tests confirmed in general those obtained in transverse tests.

90. Projectile penetration of thin armor. L. THOMPSON and E. B. SCOTT, Naval Proving Ground, Dahlgren, Va.—Penetration data are usually compared on the basis of striking energy, and the limiting velocity (just sufficient for complete penetration) is determined by experiment in which it is attempted to secure a "straddle." The

energy absorbed by a plate is evidently a function of the velocity of impact. Results obtained with plates of one class have indicated that limiting velocities may be represented to advantage by means of the relation: $V=(psd^2/M\cos\theta)\ F(s/d,\theta)$ (V, limiting velocity, θ, angle of obliquity, s, plate thickness, d, projectile diameter, M, mass of projectile). F is a slowly varying coefficient expressing the ratio of normal momentum required to that for some definite set of values of s/d and θ. P is a specific value of normal momentum per unit volume of button punched. A number of rounds fired at thin plate with large angles of obliquity were averaged by means of this expression. Results showed unexpected co-ordination with thick plate data for small angles, in view of the tendency of thin plate to bend and dish with oblique impact.

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