

PROCEEDINGS  
OF THE  
AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE FORTY-SEVENTH MEETING.

A REGULAR meeting of the Physical Society was held in the Palmer Laboratory of Princeton University on Saturday, October 23, 1909. President Henry Crew presided.

The following papers were presented :

1. The Relationship Between Entropy and Time. W. S. FRANKLIN.
2. The Lorentz Shortening: an Apparent Paradox. GILBERT N. LEWIS.
3. Ionization Produced by Entladungsstrahlen and Experiments on the Nature of the Radiation. ELIZABETH R. LAIRD.
4. The Effect of  $\text{NO}_2$  and Al on the Uranyl Bands and of Ca and Temperature on Neodymium Bands. W. W. STRONG.
5. The Octave Overtone from Tuning Forks. D. C. MILLER.
6. The Electrostatic Effect of a Changing Magnetic Field. J. M. KUEHNE.
7. A Modification of the Thomson-Wilson Method of Determining the Elementary Electrical Charge, and the Most Probable Value of that Charge. R. A. MILLIKAN.
8. Polarization of Röntgen Rays. WM. R. HAM.
9. A New Radiant Emission from the Spark. R. W. WOOD.
10. The Dependence of the Photo-electric Current on the Wavelength of Incident Light. F. K. RICHTMYER.
11. Kinetic Energy of Thermions. O. W. RICHARDSON.
12. Contact Difference of Potential in the Magnetic Field. E. P. ADAMS.
13. A Neglected Form of Relativity. D. F. COMSTOCK.
14. The Relation between the Velocity of Light and the Velocity of its Source. R. C. TOLMAN.
15. The Radiation from Platinum. (By title.) A. TROWBRIDGE.
16. A Characteristic of Spectral Energy Curves. (By title.) W. W. COBLENTZ.
17. The Depth of Complete Scattering of Kathode Rays in Lead and the Variation of the Depth with Velocity of the Rays. WM. R. HAM.

18. Landscapes and Still Life in Infra-red and Ultra-violet. R. W. WOOD.
19. Some Laboratory Applications of the Photo-electric Current. F. K. RICHTMYER.
20. Reflection of Slow-Speed Electrons. O. W. RICHARDSON.
21. The Temperature Radiation of Transparent Bodies. R. W. WOOD.
22. A Thermo-luminescent Glass. W. W. COBLENTZ.

ERNEST MERRITT,  
*Secretary.*

#### A CHARACTERISTIC OF SPECTRAL ENERGY CURVES.<sup>1</sup>

BY W. W. COBLENTZ.

USING the Wien spectral energy equation it can be shown that the wave-length of maximum emission can be computed from the observed spectral energy curve by taking two wave-lengths,  $\lambda_1$  and  $\lambda_2$ , corresponding to any two points where the emissivity  $E_1 = E_2$ . Paschen observed this property before the establishment of the theoretical equation. In the subsequent work of Paschen, and of Lummer and Pringsheim, this point is passed over without discussion. In fact the latter observers do not (to my knowledge) say how they obtain the point of maximum emission from the spectral energy curve.

From the beginning of my work on this subject it was observed that in computing the  $\lambda_{\max}$  by the aforesaid method the value usually decreases uniformly from a high one (several per cent. higher) when  $\lambda_1$  and  $\lambda_2$  are far apart, to a fairly constant value for  $\lambda_1$  and  $\lambda_2$  taken close together. In the spectra of metals the  $\lambda_{\max}$  was therefore computed by taking values of  $\lambda_1$ , and  $\lambda_2$  close together, assuming that the discrepancy was due to experimental error. In looking over previous work by Paschen it was found that his data indicate a similar condition. Unfortunately Lummer and Pringsheim never published a full report of their observations.

From the complete solution of Planck's equation

$$\lambda_{\max} = \frac{(\log \lambda_2 - \log \lambda_1) \lambda_1 \lambda_2}{(\lambda_2 - \lambda_1) \log \varepsilon} - \left( \frac{\log \left[ \left( e^{\frac{\alpha \lambda_m}{\lambda_1}} - 1 \right) e^{-\frac{\lambda_m}{\lambda_2}} \right] - \log \left[ \left( e^{\frac{\alpha \lambda_m}{\lambda_2}} - 1 \right) e^{-\frac{\lambda_m}{\lambda_1}} \right]}{\frac{\alpha (\lambda_2 - \lambda_1) \log \varepsilon}{\lambda_1 \lambda_2}} \right).$$

The first member on the right hand side of the equation is the usual solution for  $\lambda_{\max}$ , from Wien's equation, while the second member enters as a correction factor. This correction is never negligible even when

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

$\lambda_1 = \lambda_2 = \lambda_{\max}$  (data by extrapolation, by taking  $\lambda_1$  close to  $\lambda_{\max}$ ), where it is a minimum. This minimum correction to  $\lambda_{\max}$  amounts to 3.1 per cent. taken at a temperature of 465° C., and decreases to 1.2 per cent. at 1430° C.

From this it appears that, for a black body,  $\lambda_{\max} T = \text{const.}$  should not be found constant for all temperatures, as heretofore observed, before applying this correction.

#### POLARIZATION OF RÖNTGEN RAYS.<sup>1</sup>

BY WM. R. HAM.

A DETERMINATION, by means of electroscopes, of the relative intensity of Röntgen rays in various directions from the target, using glass tubes especially constructed to prevent error due to absorption of glass walls, absorption in target, and secondary rays. The results show a change indicating a polarization of the order of magnitude found by Barkla by indirect methods. The effect on this polarization of absorbing sheets of various materials is such as can be accounted for by assuming the Röntgen ray beams to be made up of rays of two types, one showing very little, if any, polarization.

#### DEPTH OF COMPLETE SCATTERING OF KATHODE RAYS IN LEAD AND VARIATION OF THE DEPTH WITH VELOCITY OF THE RAYS.<sup>1</sup>

BY WM. R. HAM.

SINCE Röntgen rays originate at a finite depth in the target, there is a certain amount of absorption in the target that varies in different directions. With an adjustable target this variation together with data concerning the coefficient of absorption for the material of the target for rays of the hardness under consideration, make possible the determination of the mean depth at which the Röntgen rays originate. With a sufficiently high velocity, the kathode rays are completely scattered at this depth as is known from the fact that the Röntgen rays then show practically no polarization. This depth of complete scattering is found to vary directly with the potential across the tube. At the velocity of beta rays of uranium, the depth in lead is found to be of the same order of magnitude as that found by Crowther for gold.

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

THE EFFECT OF  $\text{NO}_3$  AND  $\text{Al}$  ON THE URANYL BANDS AND OF  $\text{Ca}$   
AND TEMPERATURE ON NEODYMIUM BANDS.<sup>1</sup>

BY W. W. STRONG.

A CONTINUATION of the work upon absorption spectra has brought out some new phenomena. The absorption spectra of uranyl salts consist of twelve bands in the blue and violet. These bands are about 50 Ångström units wide, have hazy edges and are about 100 Ångström units apart. Starting from the blue end of the series the bands will be designated by the letters *a*, *b*, *c*, etc. In water solutions it is found that the bands of uranyl nitrate have shorter wave-lengths than the bands of the other salts. The following table gives the approximate wave-lengths of the uranyl bands for aqueous solutions.

*Uranyl Bands.*

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>	<i>j</i>	<i>k</i>
Nitrate.	4870	4705	4550	4390	—	4155	4030	3905	3815	3710	3600
Bromide.	4880	4720	4560	4450	4280	4160	—	—	—	—	—
Sulphate.	4900	4740	4580	4460	4332	4200	4070	3970	3850	3740	—
Acetate.	4910	4740	4595	4455	4310	4160	4070	3970	3865	—	—
Chloride.	4920	4740	4560	4460	4315	4170	4020	—	—	—	—

Some of the bands appear especially diffuse (chloride for example) and can only be measured approximately. The *a* and *b* bands come out best in the photographs.

Uranous salts are green and have an entirely different absorption spectra compared with that of the uranyl salts. Following are the wave-lengths of a few of the uranous bands for aqueous solutions.

*Uranous Bands.*

Nitrate.	6700	6470	—
Sulphate.	6730	6550	5500
Chloride.	6730	6530	5510

Becquerel (Commun. Phys. Lab. Univ. Leiden, Nos. 110, 111) gives the following wave-lengths of the phosphorescent bands of some uranyl salts at a temperatures of 80°(K.).

In the case of the phosphorescent bands there are several series of bands. From these three tables it seems that the  $\text{NO}_3$  group possesses an

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

influence upon the frequency of vibration of the absorbing or emitting vibrators of the uranium compound. If it were possible to find the value of  $e/m$  for these vibrators it might be possible to find the force exerted by the  $\text{NO}_3$  group upon each vibrator. It is quite remarkable that within widely different concentrations the wave-length of the uranyl bands do not change. Probably only a small percentage of the  $\text{NO}_3$  groups take part in a light absorption or emission and these may possess properties that are quite different from those of the greater number of  $\text{NO}_3$  groups.

*Uranyl Phosphorescent Bands.*

Nitrate.	—	5069.6	5301.5	5554.6	5832.9	—
Sulphate.	4918.3	5133.9	5369.4	5626.8	5910.1	6219.5
Double acetate, uranyl and sodium.	4932.5	5148.6	5384.5	5642.7	—	—

The addition of sufficient aluminium chloride to a water solution of uranyl chloride or of calcium chloride to a methyl alcohol solution of uranyl chloride is found to cause the  $d$  and  $e$  bands to come together, so as to form a single wide band and to cause the other uranyl bands to change their positions so that the resulting series of bands is almost the same as that of uranyl chloride in ethyl alcohol. The general effect of the presence of calcium and aluminium is to shift the first bands ( $a$ ,  $b$ , etc.) of the series towards the red.

Rise of temperature ( $0^\circ$  to  $90^\circ$  C.) causes very little if any change in the wave-length of the neodymium bands. The bands at the higher temperatures are invariably broader. When calcium chloride is present many of the neodymium bands narrow with rise of temperature and are shifted towards the red. It may be possible that many of the temperature and Zeeman effects found by Becquerel are due to the presence of foreign bodies in the neodymium and erbium compounds with which he worked. It is also possible that the presence of calcium in the sun might alter the Zeeman effect so that the strength of field required to produce a given separation would be different from that required in the laboratory where only pure substances are used.

#### THE KINETIC ENERGY OF THE THERMIONS.<sup>1</sup>

BY O. W. RICHARDSON.

THE present investigation is a continuation of one published in the *Philosophical Magazine* (Dec., 1908) under the title of "The Kinetic Energy of the Ions Emitted by Hot Bodies." The apparatus

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

used involves the same principles as that already employed but it has been greatly improved in detail. The increased accuracy of measurement and the greater extent to which the theoretical conditions are satisfied enable the author's previous conclusions to be subjected to a more rigorous test. In particular the spreading out of the negative electrons emitted by a narrow strip in the absence of an electric field has been examined and is found to agree very satisfactorily with the distribution which was predicted in the earlier paper, on the assumption that the distribution of velocity among the electrons is in accordance with Maxwell's law.

It is found however that at points at a considerable distance from the center of the system the current through the slit is in excess of the theoretical requirements. The discrepancy is found to be much greater when an electric field is applied between the two plates than when the field is absent. It appears to be due to the reflection of the electrons at the surface of the receiving plates. This difficulty does not appear to arise when the "sideways kinetic energy" of the positive ions is being measured.

#### THE REFLECTION OF LOW-SPEED ELECTRONS BY METAL SURFACES.<sup>1</sup>

BY O. W. RICHARDSON.

**I**N the author's investigations of the properties of the electrons emitted by hot bodies phenomena have frequently arisen which have only seemed capable of explanation on the view that the slow-speed electrons dealt with gave rise to a reflected or secondary radiation when they struck a metal surface.<sup>2</sup> The present communication describes an experiment in which the result of this reflection is exhibited using electrons whose speed corresponds to a fall of potential of 8 volts. Indirect evidence is also adduced in favor of the view that the unaccelerated electrons also give rise to a similar effect. Their speed corresponds to a fall of potential of about .03 volt. It appears that this reflection has previously been observed by von Baeyer<sup>3</sup> who concluded that the effect occurred with speeds corresponding to 5 volts and upwards.

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

<sup>2</sup> See for example *Phil. Mag.* [6], vol. 16, 761, 1908, and later papers in the same journal.

<sup>3</sup> *Ber. Deutsch. Phys. Gesell.*, 10, 4, p. 96, 1908.

ON THE ELECTROSTATIC EFFECT OF A CHANGING MAGNETIC FIELD.<sup>1</sup>

BY J. M. KUEHNE.

A CHARGED body suspended in a changing magnetic field, or better in a field swept by magnetic lines of force, should, according to the electro-magnetic theory of Maxwell and others, be subjected to a force at right angles to the lines of magnetic force as well as to the direction of their motion. The magnitude of this force will depend on the product  $Q \cdot dN/dt$ , where  $Q$  is the quantity of the charge and  $dN/dt$  the rate at which magnetic lines are moving across the space occupied by the charge.

The apparatus used in the experiment consists of a parallel plate condenser having twenty pairs of ring-shaped plates — the one set of plates is suspended free to rotate, the oppositely charged plates are stationary. Through the centers of both sets of plates passes one limb of the closed magnetic circuit of a transformer. The magnetic circuit is excited by an alternating current, and the condenser is charged from the secondary of a potential transformer, whose primary is connected in parallel with the magnetic circuit. The charged plates are thus subjected to a torque whose value, according to theory, is  $L = \frac{1}{2}nNCE$ , where  $n$  is the frequency of the alternating magnetic field,  $N$  the maximum magnetic flux through the transformer core,  $C$  the capacity of the condenser, and  $E$  the maximum charging e.m.f.

$E_1$	$E_2$	$L$	$L'$
600	.345	.33	.26
606	.342	.33	.35
606	.490	.47	.45
600	.492	.47	.44
956	.345	.52	.48
956	.348	.52	.46
806	.444	.56	.53
772	.485	.59	.57
828	.490	.64	.63
840	.494	.65	.64
848	.495	.66	.67
864	.485	.66	.73
916	.490	.71	.66
956	.474	.72	.70
956	.490	.74	.72
956	.492	.74	.72
1,294	.480	.98	1.05
1,314	.498	1.03	1.04

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society October 23, 1909.

In the experiment  $N$  was varied between 127,000 and 190,000 lines, and  $E$  between 850 and 1,860 volts, the other factors remaining constant. The effect was thus tested over a range of variation of more than 3 : 1, and throughout this range the observed torque was in satisfactory agreement with that demanded by theory, both in direction and magnitude. The observed torque was measured by rotation of the torsion head through a known angle, the moment of torsion of the suspending fiber being known.

In the following table of results  $E_1$  indicates the "effective" charging E.M.F.,  $E_2$  the effective E.M.F. induced by the magnetic field in each turn of a coil surrounding the magnet core,  $L$  the torque in dyne cm. calculated from theory, and  $L'$  the observed torque.

#### IONIZATION PRODUCED BY ENTLADUNGSSTRAHLEN AND EXPERIMENTS ON THE NATURE OF THE RADIATION.<sup>1</sup>

BY ELIZABETH R. LAIRD.

THIS work is a continuation of that previously reported. Experiments have been made to show that the effect of Entladungsstrahlen cannot be due to dust driven from the electrodes, nor to electrostatic induction, nor to a mechanical pressure wave, nor to light of wave-length greater than 1,000.

Other experiments show that the same radiation ionizes the gas through which it passes, since the ionization is increased in proportion to the thermoluminescence, and is transmitted or not by substances according as they transmit or cut off thermoluminescence, and remains unchanged under conditions in which the thermoluminescence is unchanged. In particular the ionization is cut off by thin quartz. It is much increased by the presence of certain vapors, notably turpentine, ammonia, ether, methyl iodide. The radiation appears to be reflected very slightly, but is reflected in about the same degree by such various substances as paper, lead, copper, glass. Some experiments seem to show that the penetrating power of the radiation differs according to the source used. A fuller report will appear shortly in this journal.

MOUNT HOLYOKE COLLEGE.

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

A NEW MODIFICATION OF THE CLOUD METHOD OF MEASURING THE ELEMENTARY ELECTRICAL CHARGE, AND THE MOST PROBABLE VALUE OF THAT CHARGE.<sup>1</sup>

BY R. A. MILLIKAN.

THIS modification of the cloud method of determining  $e$  consists :  
 1. In making observations, not upon the surface of a cloud, but upon single isolated drops carrying multiple charges.

2. In exactly balancing gravity upon these single charged drops by an electrical field.

3. In observing the rate of fall of these same drops under gravity after the electrical field has been thrown off.

4. In eliminating any possible error due to evaporation by first obtaining stationary, *i. e.*, balanced, drops, and then measuring the times of passage of these same drops across equal spaces in the field of the reading telescope.

5. In directly measuring the temperature of the cloud chamber instead of computing it. (It is this computation which was found to have introduced the chief error into preceding determinations of  $e$  by the cloud method.<sup>2</sup>)

In obtaining the results herewith reported the distances through which the falling drops were timed varied from 1 mm. to 1.55 mm.; the times of fall through these spaces from 3 to 5 seconds: the distances between the plates to which the potentials were applied from 4.63 to 5.45 mm.: the intensities of the electrical fields from 14 to 17 absolute electrostatic units: the liquids used for forming drops were alcohol and water.

The method compares favorably in directness and precision with any which has thus far been used for determining  $e$ . The results of 7 very concordant observations on water drops carrying triple positive charges gave  $e = 4.59 \times 10^{-10}$ : of 11 concordant observations on alcohol drops carrying double positive charges gave  $e = 4.64 \times 10^{-10}$ : of 10 observations on water drops carrying quadruple positive charges gave  $e = 4.56 \times 10^{-10}$ : of 5 observations on water drops carrying quintuple positive charges gave  $e = 4.83 \times 10^{-10}$ : of three observations on water drops carrying sextuple positive charges gave  $e = 4.69 \times 10^{-10}$ : of two observations on water drops carrying double positive charges gave  $e = 4.87 \times 10^{-10}$ . The weighted mean of these results is  $4.65 \times 10^{-10}$ . The error in this determination is estimated as not more than 2 per cent. Mr. Begeman has just completed in this laboratory a very long and careful series of observations by the regular Wilson method timing however the layers corresponding to multiple charges, and obtains as his final mean  $e = 4.66 \times 10^{-10}$ .

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

<sup>2</sup> Millikan and Begeman, *PHYS. REV.*, 26, p. 197, 1908.

The mean of all the recent determinations of  $e$  by methods which seem least open to question is given below.

Planck.....	4.69
Rutherford and Geiger.....	4.65
Regener .....	4.79
Millikan .....	4.65
Begeman.....	4.66
	Mean $e = 4.69 \times 10^{-10}$

### A THERMOLUMINESCENT GLASS.<sup>1</sup>

BY WM. W. CORLENTZ.

AN experimental demonstration of a thermoluminescent glass made of feldspar, formed into a perfectly transparent rod which was heated electrically. The luminescence appears as a faint white cloud, at a temperature of about 800° C., which increases in intensity with rise in temperature. The important point illustrated was that the light is white at all temperatures, *i. e.*, it does not pass through the usual chromatic changes found in the radiation from opaque substances which would appear red at these temperatures. The absorption and behavior in a magnetic field will require further investigation.

### THE DEPENDENCE OF PHOTO-ELECTRIC CURRENT ON WAVE-LENGTH OF INCIDENT LIGHT.<sup>1</sup>

BY F. K. RICHTMYER.

USING the apparatus previously described<sup>2</sup> the author has investigated the relation between wave-length of the incident light and the resulting photo-electric current from a sensitive sodium surface. The spectrum of a Nernst glower was thrown on the sensitive surface by means of a spectrometer with a slit substituted for the eyepiece and the resulting photo-electric currents measured by the rate of drift of an electrometer from  $\lambda = .65 \mu$  to  $\lambda = .42 \mu$ .

More satisfactory results were obtained by use of the spectrum of acetylene. In this case the observed currents were corrected for (1) variable dispersion of the prism and (2) energy distribution in the spectrum of acetylene. The curve plotted between corrected photo-electric currents and wave-lengths is similar to the visibility curve but has a maximum at  $\lambda = .46 \mu$ , suggesting resonance in some form with the free period of the electrons in the atom of sodium in its solid state corresponding to the period of  $\lambda = .46 \mu$ .

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.

<sup>2</sup> PHYS. REV., Vol. XXIX., pp. 71-80.

Computation of the energy changes involved shows that, in a certain case, while approximately 100 ergs per second of energy were absorbed from the incident light, the energy of the expelled electrons was less than one erg per second.

#### LABORATORY APPLICATIONS OF THE PHOTO-ELECTRIC CURRENT.<sup>1</sup>

By F. K. RICHTMYER.

THE production of measurable photo-electric currents from a sodium surface by extremely feeble illuminations recommends this phenomenon for use in making photometric measurements of monochromatic or of isochromatic light sources where observations by eye are extremely difficult. For example the author has studied the decay of phosphorescence of a sample of Balmain's paint for a period of over one hour following a half-minute excitation by sunlight. The curve is of the usual form and when plotted with  $1/\sqrt{I}$  as ordinates, shows three distinct linear branches.

It is also pointed out that this combination of photo-electric cell and electrometer acts as a time integrator for light intensity in much the same way that an electrolytic cell would measure total quantity of electricity. In this connection the cell might be used to study short decay phosphorescence or, as has been done by the author, to measure the *total* quantity of light passing through a photographic shutter on exposure.

<sup>1</sup> Abstract of a paper presented at the Princeton meeting of the Physical Society, October 23, 1909.