Here put $\frac{d\alpha_r}{dt}$ for u_r and u_n for u_s , so that u_n denotes the component of $\mathbf{u}_n$ in the direction of the x axis.

$$\frac{1}{2c^2} \left(\frac{d\alpha_r}{dt} \right)^2 = \frac{1}{2} u_n \frac{dL_0}{du_n} + \frac{1}{2} u_n \sum_{r=1}^{r=\infty} \alpha_r F_{rn},$$

or

$$\frac{1}{2c^2} \left(\frac{d\alpha_r}{dt} \right)^2 = \frac{1}{2} u_n \frac{dL_0}{du_n} + \frac{1}{2} \frac{u_n}{c} \int F_{1x} \rho dr_n. \quad (38)$$

F_{1x} denoting the x component of F_1 . Each degree of æther has the same kinetic energy equal to the kinetic energy of each material degree of freedom. In the latter the gyrostatic term reappears as the second part of (38). Thus the kinetic energy of the electron so far as it is electromagnetic in origin is not any part of the total energy H .

It will be objected that what appears as radiation in this paper is not the real radiation. The field immediately surrounding an electron ought to be reckoned as part of the electron's energy. If, however, we attempt thus to distinguish radiation from what is not radiation, the result is a set of equations which do not belong to a dynamical system at all. With that I am not here concerned, my object has been to consider the results of the general dynamical method wherever it is adopted.

IV. *On the Ionization of the Atmosphere due to Radioactive Matter.* By A. S. EVE, M.A., D.Sc., McGill University, Montreal*.

THERE has been quite recently a well-marked advance in the accuracy of the determination of important radioactive constants. This progress is due to improvement in method and technique, and also to the cumulative evidence derived from different types of experiments. Three notable instances may be given: the determinations of the electronic charge, of the rate of discharge of α particles from a gramme of radium, and of the number of ions produced in air by the various types of α particle.

It is therefore now possible to estimate, with a reasonable degree of accuracy, the relation in atmospheric electricity between the radioactive agents and the ionizing effects attributable to them. A balance-sheet may be attempted between cause and effect; and although it will not be possible here to review all the valuable work done by many observers

* Communicated by the Author.

in the past few years, yet we may concentrate the best results together, ascertain the measure of success attained by the radioactive theory of the ionization of the atmosphere, and indicate those outstanding difficulties which require further explanation and investigation.

At the outset it may be stated that the radioactive theory of atmospheric ionization holds the field, and that in most respects it appears sufficient and satisfactory. Yet there are some particulars in which this theory is defective or lacking, so that either there may be causes still undetermined, or our knowledge of the ascertained causes must be incomplete. Also we will consider only normal atmospheric conditions, and not such abnormal ones as thunder-storms—recently explained by Simpson as sometimes due to vertical air currents causing the breaking of water-drops with the well known consequent ionization.

In this paper the value of the electronic charge e will be taken as 4.6×10^{-10} electrostatic unit, and all numerical results will be given on that understanding. Also the value of α , the coefficient of recombination of small ions, will be taken as $3420e$ or 1.57×10^{-6} , at standard temperature and pressure. When the ionization is steady, there will be the well-known relation $q = \alpha n^2$ between q the rate of production of ions and n the number of small ions actually present, in each case per cubic centimetre. So that we have the following table for the corresponding values of q and n .

q .	n .	q .	n .
1	800	5	1784
1.57	1000	6	1960
2	1131	6.28	2000
3	1386	9	2400
4	1600	14.13	3000

Unfortunately these simple relations rarely if ever exist in the atmosphere, because many small ions become transformed into large ions owing to the presence of water vapour, dust, mist, smoke, or other physical impurities in the atmosphere. Recombination is thus delayed, and the number of ions present is exceedingly variable and hard to determine. Other difficulties arise when we seek to determine q , the rate of

production of ions per cubic centimetre, for then an electroscope must be employed, and at once there is an uncertain factor, namely the ionization due to the intrinsic radiation from the sides of the employed vessel, probably attributable to radioactive matter in the walls of the electroscope. Moreover we are seeking for the value of q in free air, while in the electroscope the ionization is in part due to the secondary rays (β rays) from the electroscope, and this secondary radiation from the walls is in excess of that from free air. Recollecting all these pitfalls, we will commence with a careful estimate of the rate of production of ions due to the radium products known to be present in the atmosphere.

Alpha Rays in the Atmosphere.

The most simple and accurate method of measuring the amount of radium emanation in the atmosphere is that of collecting the emanation either by adsorption, using coconut charcoal, or by condensation with liquid air. The results obtained are in fairly good agreement.

Eve *	60
Satterley*	100
Ashman†	89
Mean	<u>83</u>

We will select 80 as the mean value, and state that one cubic metre of the atmosphere near the earth's surface contains the amount of radium emanation in equilibrium with 80×10^{-12} gramme of radium‡. (1)

There are of course considerable fluctuations with time and position, due to barometric pressure, wind, rain, and to the varying radium-contents of the underlying soils, so that it is only an approximation to the mean value which is here quoted. It is marvellous that the properties of this gas are such as to enable us to detect its presence and measure its amount, when it constitutes less than one thousand million billionth ($1/10^{19}$) part of the atmosphere.

From the results of Rutherford and Geiger§ we can now calculate the number of ions produced per cm^3 , due to radium

* Phil. Mag. Oct. 1908.

† Amer Journ. Sci., Aug. 1908.

‡ i. e. 80×10^{-12} Curies.

§ Proc. Roy. Soc. July 1909.

emanation, A and C, in the atmosphere, namely,

$$\begin{aligned} & 80 \times 10^{-12} \times 3.4 \times 10^{10} (1.74 + 1.87 + 2.37) 10^5 \text{ per m.}^3, \\ \text{or } & 8 \times 3.4 \times 5.98 \times 10^4 \text{ per m.}^3, \\ \text{or } & 1.63 \text{ ions per cm.}^3 \text{ per sec., (2)} \end{aligned}$$

Thorium and Alpha Rays.

We are not in a position to make any such accurate calculation for thorium. It is known, however, that the active deposit due to thorium on a negatively charged wire is, on an average, about 60 per cent. of that due to radium; and we may perhaps guess, for it is little better than a guess, that the α rays from the thorium products in the atmosphere will contribute about, and not more than,

$$1.00 \text{ ion per cm.}^3 \text{ per sec. (3)}$$

Gamma Rays from RaC in the Earth.

Next the reasonable assumption will be made that the penetrating radiation, discovered by Rutherford, Cooke, and McLennan, is γ radiation due to the presence of uranium, radium, and thorium. It is noteworthy that the amount of the radioactive products in the soil is of the right order of magnitude to account for the ionization effects due to the penetrating radiation, at least near the earth's surface; also that the amount of radium emanation is of the right order to account for the active deposit which may be collected on a negatively charged wire. These relations encourage the belief that we are dealing with a true cause. It has also been shown repeatedly that the natural leak of an electroscope may be decreased in rate by surrounding it with screens of lead or water. Thus McLennan and Wright at Toronto have found that the water and ice of Lake Ontario form an efficient screen from the rays from the radioactive matter in the land beneath. F. W. Bates has verified this result over the ice on the River St. Lawrence near Macdonald College, and Gockel also has repeated the observation in a boat over a Swiss lake. There is therefore abundant and certain evidence that at least a part of the ionization of the air in an electroscope is due to γ rays from the radioactive matter in the earth. When we come to examine this question in more detail there are several points of considerable importance and interest.

We will first quote C. S. Wright's figures (Phil. Mag. Feb.

1909), obtained at Toronto over the land, and over the ice on Lake Ontario, correcting them for the new value,

$$e = 4.6 \times 10^{-10}.$$

	Lead.	Zinc.	Aluminium.
Over ice, Lake Ontario	6.4	4.4	4.8
Over land, Toronto.....	9.8	8.2	7.7
Difference	3.4	3.8	2.9

(4)

This indicates a difference of about 3 ions per cm.³ per sec. within an aluminium electroscope due to the penetrating rays from the earth near Toronto. We have now to consider what would be the effect in free air, where the secondary radiation is less than in a metal electroscope. If radium is placed outside electroscopes of different metals the ionization within is dependent on the nature of the metal employed. Thus four observers have found, to an arbitrary scale :—

	Wright.	Soddy.	Bragg.	Eve.
Lead	100	100	100	100
Zinc	81.5	75	55	63
Aluminium	71.5	57	49	54

wherein the variations between observers are no doubt largely due to different dispositions of apparatus. McLennan found that in lead the secondary radiation was twice that due to the primary, but in aluminium one-half. On the other hand, W. Wilson found that in aluminium the secondary radiation gave rise to six times as much ionization as the primary; but his apparatus was not altogether satisfactory for this determination. Some experiments which I am making, not yet completed, seem to indicate that the ionization in an aluminium electroscope is only ten to twenty per cent. more than in free air; and Bragg finds that the ionization in a cardboard electroscope is about the same as in free air. He advocates the view that the primary γ rays do not ionize at all, but give rise to secondary β rays, and that these alone produce ionization. From Wright's figures we may therefore conclude that in free air the penetrating rays from the radioactive matter in the earth generate about

$$2.5 \text{ ions per cm.}^3 \text{ per sec.} \quad . \quad . \quad . \quad (5)$$

This value is smaller than that found by several observers for the total ionization due to the penetrating radiation as determined by complete screening with lead or water. This fact suggests that a considerable part of the penetrating radiation might come from the radioactive matter in the air. Subsequently it will be shown, however, that such a conclusion appears altogether untenable, according to the present state of our knowledge and information.

Theoretical Consideration.

If there be a quantity Q grammes of *radium* at a point source, then the ionizing effect at a distance r in free air will be proportional to $Q/r^2 e^{-\lambda r}$, where λ is the coefficient of absorption of the γ rays in air. If N is the rate of production of ions in a cubic centimetre, we may write $N = KQ/r^2 e^{-\lambda r}$. This constant K was measured by me* with a fair degree of accuracy, and its value inside a thin aluminium electroscope is 3.4×10^9 . Its value in free air at standard pressure and temperature is therefore about 3.1×10^9 . I am hoping to evaluate shortly this somewhat important constant with more accuracy. (6)

Integrating from 0 to ∞ we can calculate the total number of ions which one gramme of radium can produce in virtue of the γ rays from the equilibrium amount of RaC. We have

$$\int_0^\infty K 4\pi r^2 dr \frac{Q}{r^2} e^{-\lambda r}, \text{ or } 4\pi QK/\lambda. \quad (7)$$

Now $\lambda/\text{density}$ is equal to .034 according to McClelland and to .04 according to Soddy. Selecting, in the present case, the former value, we have λ for air equal to .000044. Hence the total number of ions due to the γ rays from a gramme of radium in equilibrium is 8.5×10^{14} per sec. . (8)

But from Geiger's† experiment on the ions produced by α rays, we know that Ra Em, A and C in equilibrium with one gramme of radium produce 2×10^{16} ions per second, or about 23 times as many as the γ rays, so far as the radium products in the *atmosphere* are concerned. Near the earth the effect of the γ rays must be halved, so that we get a ratio of 1 to 46 or

$$\begin{array}{ll} \alpha \text{ rays Ra Em, A, C} & \dots\dots\dots 1.63 \\ \gamma \text{ rays RaC} & \dots\dots\dots .035 \end{array} \quad (9)$$

The addition for the ionization of the primary β rays is at

* Phil. Mag. Sept. 1906.
† Proc. Roy. Soc. July 1909.

present unknown, but it appears to be about equal to that of the γ rays in effect. Perhaps the distinction is an erroneous one, but in any case we obtain an estimate of this sort—

Rays.	Ra.	Th.	Total.
α	1.63	1.00	2.63
β	.035	.025	.06
γ	.035	.025	.06
	1.70	1.05	2.75

(10)

Thus 2.7 ions per cm.³ per sec. is our value for the mean total ionization, due to all the radioactive matter in the *atmosphere*, near the earth's surface. It will be seen that the α rays are mainly effective.

We can, however, calculate the ionization due to the γ rays from radium C in a more direct way than above. If N is the number of ions produced per cm.³ per sec., λ the coefficient of absorption of the γ rays by air, Q the amount of radium C per cm.³ of the atmosphere, expressed in terms of the number of grammes of radium with which it is in equilibrium, then

$$N = \int_0^\infty 2\pi r^2 dr K \frac{Q}{r^2} e^{-\lambda r} = 2\pi QK/\lambda. \quad \dots (11)$$

Here $K = 3.1 \times 10^9$, $\lambda = .000044$, $Q = 8 \times 10^{-17}$;
whence $N = 2\pi \times 3.1 \times 10^9 \times 8 \times 10^{-17} / 4.4 \times 10^{-5} \}$. (12)
 $= .035$ ion per cm.³ per sec.

This agrees with the former result (9).

It is possible to use a formula exactly similar to (11) in order to calculate the rate of production of ions near the earth's surface, due to the radium C in the *earth*. In this case K has the same value as before, but $Q' = 1.4 \times 10^{-12} \times 2.7$, the mean value found for sedimentary rocks by Strutt, and $\lambda' = .034 \times 2.7$ (McClelland).

Hence

$$\begin{aligned} N' &= 2\pi Q'K/\lambda' \\ &= \frac{2\pi \times 3.1 \times 10^9 \times 1.4 \times 10^{-12} \times 2.7}{.034 \times 2.7} \\ &= \frac{2\pi \times 3.1 \times 1.4}{3.4} \times 10^{-1} \\ &= 0.80 \text{ ion per cm.}^3 \text{ per sec.} \quad \dots (13) \end{aligned}$$

This is the calculated value of the mean ionization at a given locality, near the earth, due to the penetrating rays from the radium C in the earth. It will be nearly constant at any given place, but it will vary from place to place according to the amount of radium present in the surface soils and rocks of the more immediate neighbourhood. It may be noted in particular that the ratio of N to N' is equal to that of Q/λ to Q'/λ' , whose accented letters refer to the earth. But λ and λ' are proportional to ρ and ρ' , the densities of the earth and soil. Hence

$$N'/N = Q'\rho/Q\rho' = \frac{1.4 \times 10^{-12} \times 2.7 \times .0013}{2.7 \times 8 \times 10^{-17}} = \frac{1.4 \times 1.3}{8} \times 100 = 23. \quad (14)$$

The penetrating radiation from the earth is therefore normally about 23 times as great as the penetrating radiation from the atmosphere, at least so far as radium C is concerned. I see no escape from this conclusion*, and it appears to

* We may, however, consider an extreme case. Suppose that the active deposit of radium and thorium were distributed uniformly, as near the earth's surface, for a height of 5 kilometres; and suppose, further, that the whole of this active deposit were carried suddenly to the earth by a fall of rain. There would then be on or near the earth's surface $5 \times 10^5 \times 8 \times 10^{-17}$ or 4×10^{-11} gramme of RaC (expressed in terms of radium). This is equal to the amount of radium C in 30 or 40 centimetres of the soil, in each case per square centimetre. The thin layer of RaC derived from the atmosphere would, however, be by far the more efficient ionizer, because the γ rays would not have to penetrate through, and be absorbed by, the surface layers of the earth. The increase of the penetrating radiation during rain has been observed by Mache, and by Gockel. Such variations, however, were not found by McLennan at Toronto. The motion of RaC earthwards, not carried by a water drop, would be only about 50 metres an hour, due to the potential gradient.

I have calculated the ionization at various altitudes due to this very hypothetical surface layer of radium C, and obtain,

$$N = 2\pi qK \int_0^1 e^{-\frac{\lambda h}{z}} \frac{dz}{z},$$

whence

Altitude.	Ions/cm. ³ sec.
1 m.	1.8
10	1.05
100	.32
1000	negligible

On comparing this table with result (18) it will be seen that, in extreme cases, near the earth's surface the ionization due to the RaC carried down by rain or snow might equal or exceed that due to the RaC contained in the soil and rocks. In general, the active deposit would doubtless enter the soil with the rain.

negative the view that the penetrating radiation comes equally from all directions. So far as our knowledge of the distribution of thorium at present goes, we may also predict that a similar statement will be found to hold good for the γ rays of thorium C.

Returning to the result previously stated (13), we will next assume that the work of Blanc, Joly, W. Wilson (Phil. Mag. Feb. 1909), and others indicates that the penetrating radiations from the radium and from the thorium in the earth are about equal, and we can now set forth a complete table.

Type.	Whence.	Ra.	Th.	Total.
α rays	Air	1.63	1.00	2.63
β "	Air	.035	.025	.06
γ "	Air	.035	.025	.06
γ "	Earth	.80	.80	1.60
		2.50	1.85	4.35

(15)

This rate of production of ions per cubic centimetre, namely 4.35, corresponds to the presence of 1660 ions per cm^3 , supposing that they were all small ions. The maximum value of ions measured in clear weather by an Ebert ion-counter is usually somewhat less than this.

It must be remembered that the numbers quoted in the preceding table are subject to considerable variations both with time and place; and are only intended as a guide to the mean values, which will no doubt in due course of time be determined with an accuracy to which my estimates can of necessity make no claim.

It will be seen that the theoretical value found, 1.6 ions per cm^3 per sec. for the penetrating radiation from the earth, is less than that obtained by Wright at Toronto, namely 2.5. It is also considerably less than the number of ions per cm^3 per sec. lost when an electroscope is well screened by lead, amounting to about 6. It is true that my calculations do not take account of the feeble and negligible γ radiation from actinium, the distribution of which is unknown. Further, it has been shown by Soddy (Phil. Mag. Oct. 1909) that the γ rays from uranium X are more penetrating than was at first supposed. The addition which should on this account

be made is of an uncertain character *. An increase in the value of q will affect the value of n , which is already in excess of that observed. Yet with every allowance for the value of q , due to penetrating radiation, the theoretical value appears to be smaller than the observed. We may deduce either that the radioactive matter in the earth has been underestimated, which is improbable, or that the value found for K is too small, or that the observed values of q are too great, or that radiation exists of a type not yet expected or discovered proceeding from matter rather than from radioactive matter.

Ionization over the Ocean.

It would be interesting to make a table corresponding to that given above (15), but with values for mid-ocean. Unfortunately we have no certain measurements of the mean quantity of radium or thorium emanations over the ocean. From experiments by many observers, it appears that sea breezes on the western side of a continent contain less radium C than do land breezes. It is, however, certain that radium C does exist over the ocean in measurable quantities, and there is little doubt that radium emanation escapes from the ocean with greater facility than from the land, and this fact compensates to some extent for the minuteness of the radium contents of the ocean as contrasted with the land. There is also some uncertainty as to the mean value of the amount of radium in sea water, for Joly (Phil. Mag. Sept. 1909) has found 1.1×10^{-14} gramme of radium per cm.³ for sea-water from various localities, and I have found 10^{-15} for sea-water from the middle of the North Atlantic. For the present we will take the higher value given by Joly. The ratios of the penetrating radiations from the RaC in land, sea, and air are then, necessarily, near the earth's surface, as

$$Q/\rho : Q'/\rho' : Q''/\rho'',$$

where the Q 's denote quantities of radium C per cm.³, expressed in equivalent grammes of radium, and the ρ 's denote the respective densities.

* If equal to radium we get $3 \times 0.8 = 2.4$, agreeing with Wright, see (15).

Thus we have:—

Penetrating Radiation, RaC.

	Land.	Sea.	Air.
Q	4.3×10^{-12}	1.1×10^{-14}	8×10^{-17}
ρ	2.7	1.0	.0013
Q/ ρ	1.4×10^{-12}	1.1×10^{-14}	6.1×10^{-14}
Ratios	130	1	5.5
or	23	.18	1
Ions/cm. ³ sec.	.80	.006	.035

It will at once be seen that the penetrating radiation over the ocean from the radium in the sea is negligible, being less than one-fifth of that from the radium C in the atmosphere over land. Since the radium emanation in the atmosphere over the sea is probably less than over the land, it is altogether quite extraordinary that those observers who have used Ebert's ion-counter, and those who have measured the conductivity of the atmosphere over the sea, have found values in each case not much, if any, less than over the land. It is possible that the greater purity of the air over the ocean—the absence of dust and smoke and physical impurities of that kind—may cause the small ions over the ocean to remain small ions, except during time of actual fog, while over the land they tend to become large ions. Yet such an explanation is very doubtful, and in this discrepancy lies at present our chief objection to a purely radioactive theory of atmospheric ionization. It is a question on which further investigation is needed, before any weighty opinion can possibly be hazarded.

We get a sidelight on this interesting and difficult point in the action of Hertzian waves in wireless telegraphy, which appear to have a larger effective radius in the dark, or during mist or fog, and are to a considerable extent absorbed in the presence of sunlight. It is possible that the small ions both render the air a conductor and tend to absorb or disperse the Hertzian waves, and that the sunlight may itself produce small ions. There appears to be no direct evidence of the influence of sunlight increasing the ionization near the earth's surface, but if the electrons were freed a little from the

atoms by sunlight and then returned to the parent atoms, these might account for the greater absorption of the Hertzian waves during the daytime. The ultra-violet light from the sun seems to be mainly absorbed in the upper layers of the atmosphere, so that it is not an important ionizing agent near the earth's surface. Further observations are needed on this point.

Effect of Altitude.

In conclusion we have to discuss the effect of elevation on the radiation from the radium C in the earth. The γ rays are absorbed rapidly in the earth, slowly in the air, and the ratio of the coefficients of absorption is nearly that of the densities, or as 2.7 is to .0013, about 2000 to 1. So that 1 cm. of the soil is as effective as 20 metres of air. In the case of a point source of radium C the law of inverse square of the distance also obtains, so that the radiation at a distance r from the source varies inversely as $r^2 e^{\lambda r}$. Hence if with such a point source the radiations were represented by 100 at 1 metre, there would be a rapid decrease with distance thus

At 1 metre, radiation 100.

10	"	"	.95
100	"	"	.0064
1000	"	"	.000012

But in the case of the earth we have a *sheet* of radioactive matter, distributed with some approach to uniformity through the surface layers, which alone is effective in the atmosphere. The calculation has not, I think, yet been given, and therefore it is set forth here with some fulness.

Let P (fig. 1) be a point at elevation h above the earth's

Fig. 1.

surface, assumed plane. Let Q grammes of radium be the contents per cm.³ in the earth. Consider an elementary ring dx by dY , radius x , at a depth Y below the surface. Then

the ionization at P will be

$$\begin{aligned}
 & \iint \frac{2\pi x dx dy QK}{(r+y)^2} e^{-\lambda'y} e^{-\lambda r}, \\
 & \text{where } y \text{ is small compared with } r, \\
 & = \iint_0^\infty 2\pi QK \frac{h \cot \theta \cdot h \operatorname{cosec}^2 \theta d\theta}{h^2 \operatorname{cosec}^2 \theta} e^{-\lambda h \operatorname{cosec} \theta} e^{-\lambda'Y \operatorname{cosec} \theta} dY \\
 & = 2\pi QK \int_0^{\pi/2} \frac{\cot \theta d\theta}{\lambda' \operatorname{cosec} \theta} e^{-\lambda h \operatorname{cosec} \theta} \\
 & = \frac{2\pi QK}{\lambda'} \int_0^{\pi/2} \cos \theta e^{-\lambda h / \sin \theta} d\theta \\
 & = \frac{2\pi QK}{\lambda'} \int_0^1 e^{-\lambda h/z} dz. \quad \dots \dots \dots (17)
 \end{aligned}$$

In order to evaluate this troublesome integral I have drawn the curve $y=e^{-\lambda h/z}$, and determined the area from $z=0$ to $z=1$, for various values of h , and substituted the values of λ , λ' , Q , and K given in this paper. When h is zero we have $2\pi QK/\lambda'$, agreeing with our former work.

Thus the numbers of ions produced per cm.³ per sec. at various altitudes by the penetrating radiation due to radium C in the earth is given in the following table:—

Height in metres.	Penetrating Radiation.	
	Ratio.	Ions per cm. ³ per sec.
0	1·00	·80
1	·98	·78
10	·83	·67
100	·36	·29
1000	·001	·008

(18)

The values in the right column should perhaps be doubled if we add the effect of thorium to that of radium.

In this calculation I have not made any correction for the decrease of density of the air with increase of altitude. This would tend to *augment* the lower figures, because the rays would be less readily absorbed; but, on the other hand, the number of ions produced would be *diminished* with a decrease of pressure

The results shown in the table (18) are very remarkable. They indicate a decrease of ionization with altitude which is within the limits of detection for an elevation of 100 metres. They show, moreover, that at 1000 metres altitude the penetrating rays from the earth are ineffective as an ionizer. This result cannot well be put to the proof by ascending a mountain, because the radium contents of the ground beneath the observer are changing as he ascends. The experiment may be commended to those who are able to fly kites or captive balloons for 24 hours at a few hundred metres. It would be necessary to have an electroscope with a low natural leak and insulation of a high order fortified with a guard ring. Gockel has made observations in a balloon (not captive) at an altitude of 4000 metres on the penetrating radiation and found but a *moderate* decrease in the saturation current of an electroscope, carried upwards in the balloon. There are, as he points out, difficulties and uncertainties in making such measurements.

It will be seen from this paper that the radioactive theory of the ionization of the atmosphere is gradually approaching what may almost be termed an exact science, but that there are three outstanding problems of difficulty and importance. These are: (1) the high value of the ionization over the ocean is not yet explained (n is larger than expected, q is unknown); (2) the rapid decrease of ionization with altitude has not been detected; (3) the theoretical value of the ionization due to the penetrating radiation is *less* than that found when observers completely screen an electroscope with lead.

Until these three questions have been satisfactorily explored we cannot rest wholly content with the theory, but have a vague feeling that all matter may give rise to feeble rays of the Röntgen type, of which the more penetrating may integrate into an effective total. This last view is by no means advocated by the writer.

Last May I attempted some measurements on the North Atlantic, and found that in a cabin of the iron s.s. 'Dominion,' in mid-Atlantic, the leaf of an electroscope closed a little more slowly than on land, indicating a slight decrease of penetrating radiation over the ocean. But I regret to add that the inherent difficulties of observations on shipboard prevented me from reaching any exact or convincing results.

The writer will be grateful for any information or suggestions tending to correct the somewhat tentative values given in this paper.

July 1910.

Note added Oct. 26, 1910.

Since this paper was written there have appeared two communications by Wulf (*Le Radium*, June 1910; *Phys. Zeit.* 15 Sept. 1910). These throw much light on the subject of penetrating radiation and confirm some of the conclusions set forth above.

Wulf, with the vessels he used, finds for the penetrating radiation in Holland $q=10$, in Paris $q=6$, and at a height of 300 m. on the Eiffel Tower $q=3.5$.

The reduction in q over a lake was about 4.9, and a similar reduction was determined at a depth of 12 m. beneath the surface of the water. His interesting experiments seem to establish the terrestrial origin of the penetrating radiation and the diminution of intensity with altitude.

The figures appear to require reduction for values in free air, perhaps on the basis of lead 100, zinc 60, aluminium 52, free air 42.

It will be seen that Wulf's value for q , even at Paris, is larger than that calculated in this paper, and that a loss of 40 per cent. for an altitude of 300 m. is less than the loss of 64 per cent. which I calculate for an altitude of 100 m. It will no doubt take time to reconcile these points.

At present it would seem that the penetrating radiation both passes through the air more readily, and also produces more ions than laboratory experiments, with Ra C and metal screens, lead us to infer. It will, however, be remembered that no direct measurements of the coefficient of absorption of the γ rays by gases have yet been made. A. S. E.

V. *Note on the Ratios which the Amounts of Substances in Radioactive Equilibrium bear to one another.* By HUGH MITCHELL, M.A.*

(1) **T**HE law of radioactive change is that the rate of disintegration of an active substance is proportional to the amount of it present. A series of radioactive substances is said to be in equilibrium when the ratio of the amount of one substance to that of any other substance in the series remains unchanged as time goes on. It is known that assuming the disintegration rate of the parent substance to be small in comparison with that of any other in the series, the ratio of the amounts of any two substances in the series is approximately equal to the ratio of their average lives. The present note is intended to show that without

* Communicated by F. Soddy, M.A., F.R.S.