Transmutation of Elements and Induced Radio-Activity.

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THE alchemists of old had only dreamed of one artificial transmutation, *viz.*, that of the baser metals into gold. But modern Physics has witnessed wonderful transmutations far beyond the vision of the most visionary alchemist. The last year in particular has brought forth such a wealth of new and astounding results that to-day, we have already great difficulty in giving a resumé in a few pages. New discoveries are being published in ever-increasing numbers so that it behoves us to take stock of our position at frequent intervals. Such a survey is particularly needed at present and the following pages will be devoted to a brief account of the most important results so far obtained.

The first artificial transmutation was achieved by Rutherford in 1919 when he bombarded nitrogen by α-particles and showed that hydrogen was produced. Blackett's cloud track photographs of this phenomenon showed that the α-particle entered the nitrogen nucleus, ejecting a proton and forming an O^{17} nucleus. The new missiles placed at the disposal of science by the discoveries of Cockcroft and Walton, Chadwick, Lawrence and Urey have rendered possible a large variety of transmutations. Our present purpose is not to discuss the results of all these experiments, but to pass on to a new discovery made by Curie and Joliot in the course of their researches in this field. We mean the production and study of new radioactive elements and the consequent enrichment of our knowledge of the nucleus. This new discovery is not only most important and interesting in itself but also because it has made it possible to produce chemical proofs of transmutation where previously one had to content oneself with considerations of the total charge and mass of the particles involved in the process and the conclusions deducible by such considerations.

The discovery of new radioactive elements was made by Curie and Joliot in the course of their investigations of the result of bombarding nuclei of the light elements by α-particles from Polonium. The experiments of Rutherford and others had showed that most of the light nuclei up to Potassium emitted protons when bombarded by α-rays, resulting in the formation of nuclei of other known elements. Now Curie and Joliot found that fluorine, sodium and aluminium also emitted neutrons when thus bombarded. Here therefore were new transmutations which could not however be explained so easily as the previous type. Thus taking the case of aluminium, we have the following equation representing the transmutation by emission of protons :

$$\overset{27}{\underset{13}{Al}} + \overset{4}{\underset{2}{He}} \rightarrow \overset{30}{\underset{14}{Si}} + \overset{1}{\underset{1}{H}} \qquad \text{.. (1)}$$
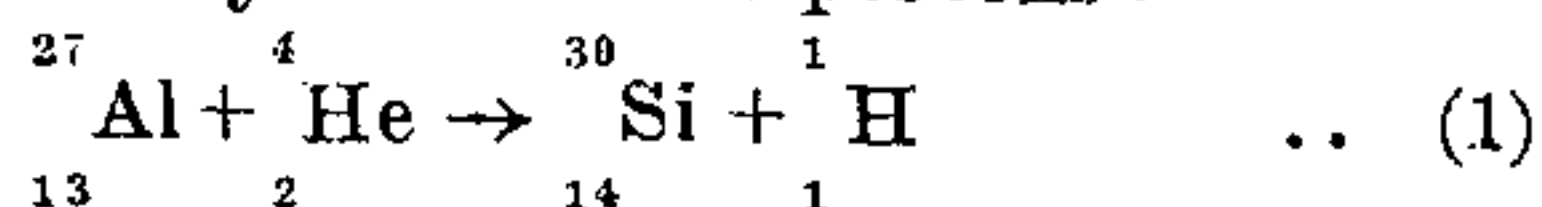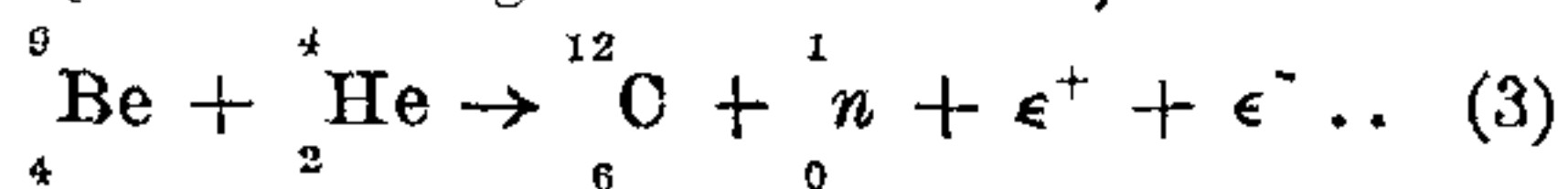
In these equations, the lower index represents the charge on the nucleus and the upper index gives its mass. The equation is such that the sums of the charges on either side balance as also the sums of the masses. Thus in the above equation, the total charge on the left is $15 = 13 + 2$, and so also on the right the sum is $15 = 14 + 1$. Similarly the mass on the left is $27 + 4 = 31$ while that on the right is equally $31 = 30 + 1$. The symbol $\overset{1}{H}$ represents the proton that is ejected during the transformation. When we try to set up a similar equation for the transmutation observed by Curie and Joliot in which neutrons were ejected, we are led to the following :

$$\overset{27}{\underset{13}{Al}} + \overset{4}{\underset{2}{He}} \rightarrow \overset{30}{\underset{15}{P}} + \overset{1}{\underset{0}{n}} \qquad \text{.. (2)}$$
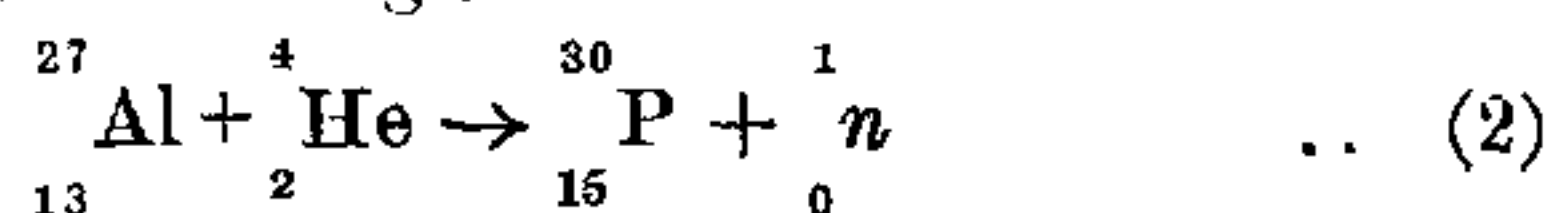
The symbol $\overset{1}{\underset{0}{n}}$ represents the ejected neutron of charge zero and mass one. The nucleus of Phosphorus of charge 15 and mass 30 which we are thus led to postulate is one which does not occur ordinarily in Nature. Hence the difficulty involved in the above explanation. This very difficulty led to important discoveries as we shall see below.

Now Curie and Joliot had already found[1] that some light elements like beryllium, boron and aluminium emit positrons when bombarded by α-particles from Polonium. In the case of beryllium they considered that the positrons were due to a materialization of the γ-rays emitted by beryllium along with neutrons, thus :

$$\overset{9}{\underset{4}{Be}} + \overset{4}{\underset{2}{He}} \rightarrow \overset{12}{\underset{6}{C}} + \overset{1}{\underset{0}{n}} + \epsilon^{+} + \epsilon^{-} \quad \text{.. (3)}$$

The symbols ϵ^{+} and ϵ^{-} represent the positive and negative electron respectively. The
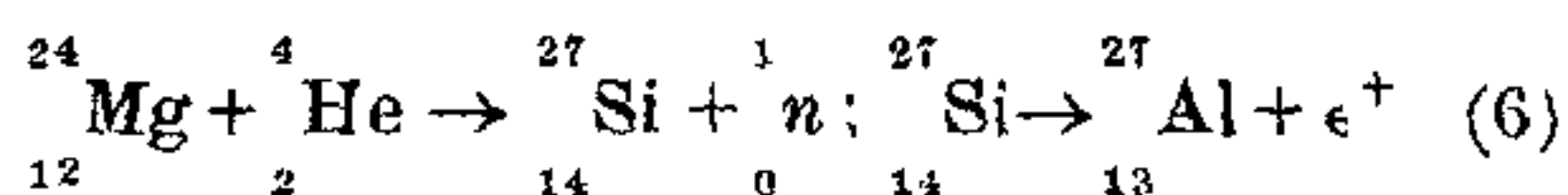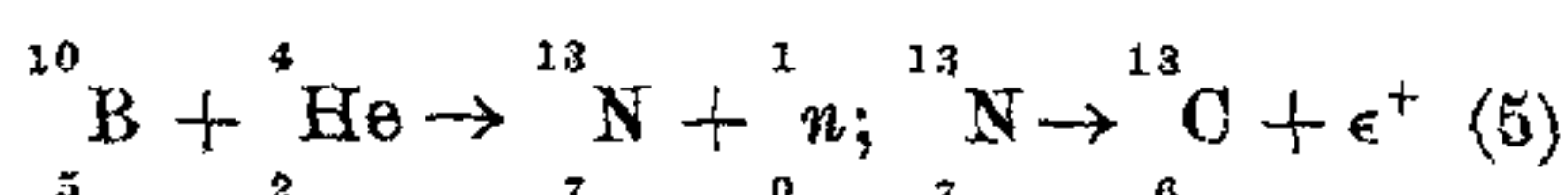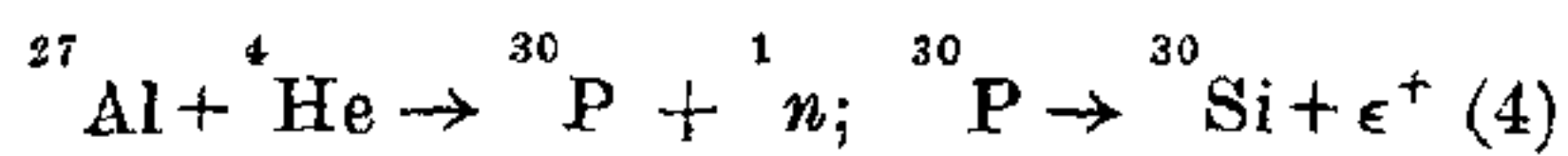
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[1] *Comptes Rendus*, 1933, **196**, 1885.

view represented by equation (3) was supported by a comparison of the energies of the positrons emitted and of the γ-rays usually accompanying the emission of neutrons by beryllium. In the case of boron and aluminium, however, they found that the positrons had to be attributed to the product which resulted from the transmutation with the ejection of neutrons. The discovery of new radioactive elements and the explanation of (2) followed at once when Curie and Joliot found[2] that the emission of positrons continued even after they had removed the source of bombarding α-rays, and that the activity, *i.e.*, rate of emission of positrons, followed an exponential law of decay as in the case of ordinary radioactivity. The explanation of (2) is now clear. We have seen that the transformation leading to the emission of neutrons necessitates the assumption of the formation of hitherto unknown nuclei such as $^{30}_{15}P$.
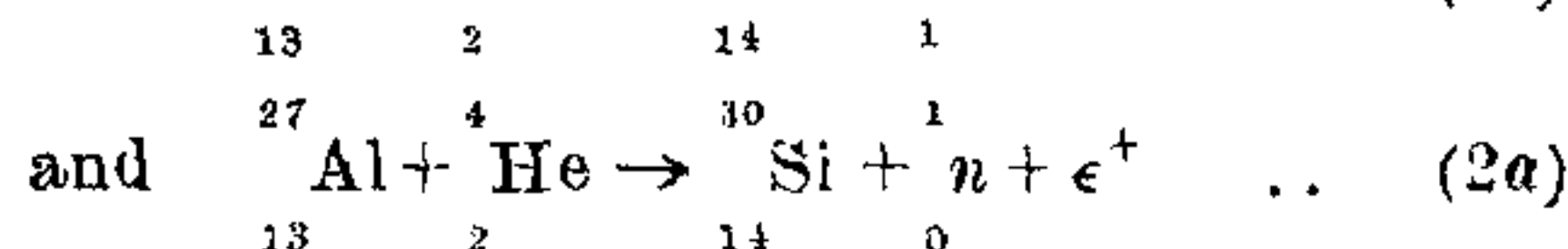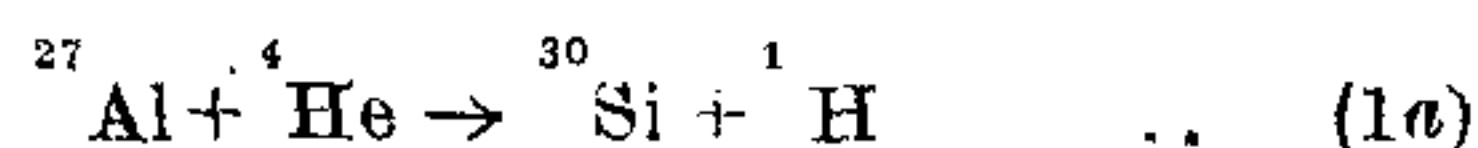
If we now assume that these nuclei are ordinarily not found because they are unstable and that they disintegrate with the emission of positrons according to the ordinary law of radioactive decay, we have an explanation of the phenomena observed by Curie and Joliot. They also observed that the decay of each of the new nuclei produced by them had a characteristic half-value period. Thus in the case of aluminium, boron and magnesium, the half-value periods were respectively 3 mins. 15 secs., 14 mins., and 2 mins. 30 secs. The nuclear reaction as envisaged by Curie and Joliot in each of these cases is as follows :

$$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n; \quad {}^{30}_{15}P \rightarrow {}^{30}_{14}Si + \epsilon^{+} \quad (4)$$

$$^{10}_{5}B + {}^{4}_{2}He \rightarrow {}^{13}_{7}N + {}^{1}_{0}n; \quad {}^{13}_{7}N \rightarrow {}^{13}_{6}C + \epsilon^{+} \quad (5)$$

$$^{24}_{12}Mg + {}^{4}_{2}He \rightarrow {}^{27}_{14}Si + {}^{1}_{0}n; \quad {}^{27}_{14}Si \rightarrow {}^{27}_{13}Al + \epsilon^{+} \quad (6)$$

The new radioactive elements thus produced were called radio-phosphorus, radio-nitrogen and radio-silicon respectively. Not content with a mere guess at the nature of the radioactive products thus formed, Curie and Joliot proceeded to establish their identity by chemical tests. This they were able to do, thanks to the radioactivity of the new elements. In all previous experiments on

artificial transmutation, the chemical nature of the product could not be established because of the extremely minute quantity of the substance produced ; in fact the product consisted of a small number of atoms and no chemical tests could be carried out on these. But the situation was now different ; although the new radioactive products were also present in equally minute quantities, their radioactivity was there to serve as an indicator. Thus if the new products were precipitated by any chemical reaction, the fact of their having been so precipitated could be established by the circumstance that the radioactivity was now associated with the precipitate. In this way the chemical tests for phosphorus and nitrogen were applied and their formation in the processes represented by (4) and (5) was thus proved. Thus for the first time, new radioactive elements were produced and their nature securely established by chemical tests.

Other workers were not slow to pursue these investigations with various modifications. L. Meitner[3] studied the reactions occurring when aluminium was bombarded by α-rays from Polonium and by means of Wilson cloud chamber photographs showed that aluminium is transformed in two ways as follows :

$$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{14}Si + {}^{1}_{1}H \qquad .. \quad (1a)$$

and

$$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{14}Si + {}^{1}_{0}n + \epsilon^{+} \quad .. \quad (2a)$$

She also showed that the first of these reactions takes place about four times as frequently as the second. This fact that aluminium disintegrates in two ways was utilised by Curie and Joliot to arrive at an estimate of the mass of the Neutron. A comparison of the above equations shows that if the energies of the proton and of the neutron and positron appearing on the right-hand side of (1a) and (2a) respectively are known, an accurate estimate of the mass of the neutron becomes possible without the necessity of accurately knowing the masses of the other nuclei taking part in the reaction. Thus if m_p and m_{ϵ^+} are the masses of the proton and positron respectively, and W_p, W_n, W_{ϵ^+}, W_u and W_n' represent the kinetic energies of the proton, neutron, positron and the recoiling silicon nucleus in (1a) and (2a) respectively, the

[2] *Comptes Rendus*, 1934, **198**, 254 & 559.

[3] *Naturwiss.*, 1934, **22**, 172.

mass of the neutron

$$= m_p - m_{\epsilon^+} + W_p - W_n - W_{\epsilon^+} + W_R - W_R'.$$

The mass of the neutron was in this way found to be 1·0092. This is higher than Chadwick's original value 1·0067 and even his revised value, viz., 1·0080 is less than the value thus deduced by Curie and Joliot. The question of the mass of these particles is important since it helps to throw light on the question as to which particle is elementary and which composite. Recently, Wentzel[4] has shown reasons to believe that the neutron may have a mass equal to that of the hydrogen atom ; we shall, however, not linger over this topic here.

A comparison of equations (1a) and (2a) further shows that since in (1a) we have one particle of spin $\frac{1}{2}\frac{h}{2\pi}$ emitted while in (2a) there are two particles each with a spin of $\frac{1}{2}\frac{h}{2\pi}$, we have, in order to satisfy the conservation of angular momentum, to assume that in (1a) another particle of negligible energy, but with a spin of $\frac{1}{2}\frac{h}{2\pi}$ is emitted. This hypothetical particle has been called an anti-neutrino just as the similar particle assumed by Fermi to be emitted during β-transformations was called a neutrino. On de Broglie's theory a neutrino and an anti-neutrino together constitute a photon of light. These questions however cannot be elaborated here.

Ellis and Henderson[5] repeated the experiments of Curie and Joliot and confirmed their results. Cockroft, Gilbert and Walton[6] have employed artificially accelerated protons as missiles to produce new radioactive elements, while McHenderson, Livingston and Lawrence[7] and Crane and Lauritsen[8] have used artificially accelerated deutons and protons and produced other new radioactive bodies. A number of these emit positrons together with γ-rays due to their annihilation. Even more interesting is the work of Fermi[9] and his collaborators. Whereas the charged missiles such as protons, deutons and α-particles employed by previous workers could be directed against light nuclei only since the greater charge on heavier nuclei prevents these charged missiles from hitting the nucleus, Fermi hit upon the idea of employing neutrons to bombard various nuclei. These neutrons, being uncharged, can penetrate even the heaviest nuclei and systematic work by Fermi and his collaborators has resulted in the production of new radioactive elements from almost all the elements of the periodic table including Uranium. In most of these cases, a β-activity with the emission of electrons is observed. In some cases, the neutron enters the struck nucleus forming a heavier isotope of the same. Apart from the regularities which these authors have pointed out, great interest attaches to their claim to have produced elements of atomic numbers 93 and 94. In most cases, they have established the nature of the radioactive products by chemical methods, but in the case of elements 93 and 94, their conclusions were called in question by A. v. Grosse. They found that when Uranium is bombarded by neutrons, new radioactive products of half-value periods, 13 mins. and 100 mins. were produced. Chemical tests were made to assure themselves that the new products were not isotopes of known elements. Grosse[10] however came to the conclusion that the chemical reactions observed with the new products were characteristic of element number 91 (Protactinium) and that the reactions which were supposed by Fermi to be opposed to such a conclusion were not conclusive at all. In view, however, of the importance of the claim put forward by Fermi, L. Meitner[11] has repeated their experiments and by a new and decisive chemical technique established beyond doubt that the new bodies are not elements of atomic number less than 92 and that the product of period 13 mins. is most probably element No. 93 ; and since her experiments show that the 100 mins. product is not an isotope of the 13 mins. product, the longer-lived product must be element No. 94. Whether the new elements beyond Uranium thus proved to exist are similar to Rhenium and Osmium or whether they belong to a family similar to the rare earths, is a question which is awaiting solution.

The discovery of Curie and Joliot has thus led to important results which are sure to increase our knowledge of nuclei and

4 Naturwiss., 1935, 23, 35.
5 Proc. Roy. Soc., A, 1934, 146, 206.
6 Nature, 1934, 133, 328.
7 Phys. Rev., 1934, 45, 428.
8 Phys. Rev., 1934, 45, 431 and 497.
9 Proc. Roy. Soc. A, 1934, 146, 483.

10 Nature, 1934, 134, 773.
11 Naturwiss., 1935, 23, 37.

atoms ; we must, however, before closing, refer to the practical utility of their discovery which Curie and Joliot have pointed out.[12] The new artificially produced radioactive elements and their radiations may in the near future displace the costly radium for therapeutic purposes, and minute traces of these radioactive bodies may be utilised as indicators in studying biological processes. Both of these happy ideas promise to produce lasting good to humanity and we may be confident that the important discoveries of Curie and Joliot will be followed up and lead to advances of vital importance in times shortly to come.

Baluchistan Earthquake of May 31, 1935.

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BARELY seventeen months have passed since the occurrence of the disastrous earthquake in Bihar and Nepal, and India is again sorely stricken by another calamitous earthquake in Baluchistan. The present note gives such preliminary information regarding the focal region and the intensity of the Baluchistan earthquake as can be gathered from the records of the Colaba Observatory alone.

Colaba Milne-Shaw seismograms of the Baluchistan earthquake are reproduced in Fig. 1 (N-S component) and Fig. 2 (E-W component). The preliminary and the
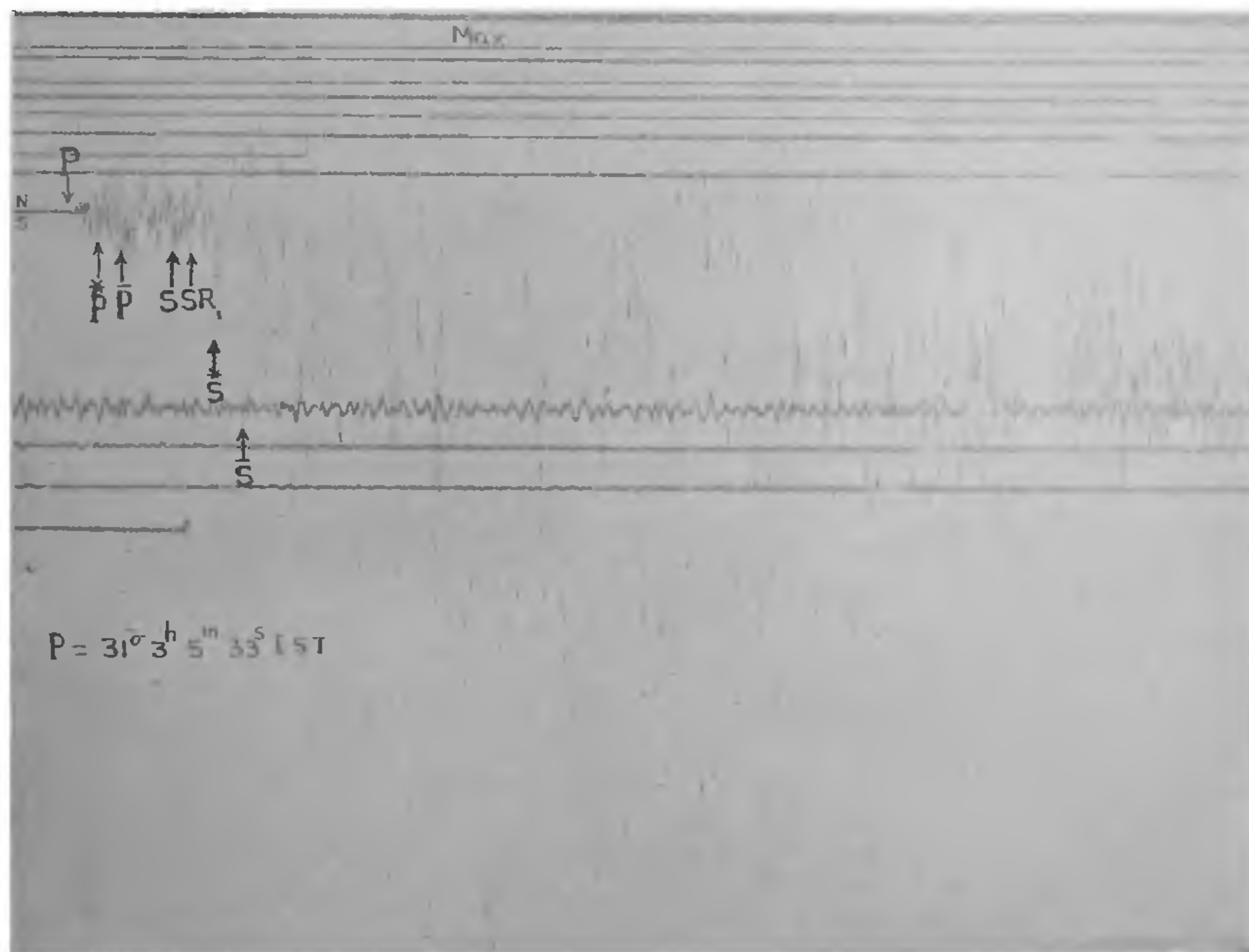

Fig. 1.

Colaba Seismogram of Baluchistan Earthquake, May 31, 1935.   Milne-Shaw North-South.

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[12] *Radioactivité Artificielle,* Hermann et Cie, Paris, 1935.