Vol. 139, 323-324

Letters to the Editor

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 332.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

The Cosmological Constants

THE fundamental constants of physics, such as c the velocity of light, h Planck's constant, e the charge and m mass of the electron, and so on, provide for us a set of absolute units for measurement of distance, time, mass, etc. There are, however, more of these constants than are necessary for this purpose, with the result that certain dimensionless numbers can be constructed from them. The significance of these numbers has excited much interest in recent times, and Eddington has set up a theory for calculating each of them purely deductively. Eddington's arguments are not always rigorous, and, while they give one the feeling that they are probably substantially correct in the case of the smaller numbers (the reciprocal fine-structure constant hc/e^2 and the ratio of the mass of the proton to that of the electron), the larger numbers, namely the ratio of the electric to the gravitational force between electron and proton, which is about 10^{39}, and the ratio of the mass of the universe to the mass of the proton, which is about 10^{78}, are so enormous as to make one think that some entirely different type of explanation is needed for them.

According to current cosmological theories, the universe had a beginning about 2×10^9 years ago, when all the spiral nebulæ were shot out from a small region of space, or perhaps from a point. If we express this time, 2×10^9 years, in units provided by the atomic constants, say the unit e^2/mc^3, we obtain a number about 10^{39}. This suggests that the above-mentioned large numbers are to be regarded, not as constants, but as simple functions of our present epoch, expressed in atomic units. We may take it as a general principle that all large numbers of the order 10^{39}, 10^{78} . . . turning up in general physical theory are, apart from simple numerical coefficients, just equal to t, t^2 . . . , where t is the present epoch expressed in atomic units. The simple numerical coefficients occurring here should be determinable theoretically when we have a comprehensive theory of cosmology and atomicity. In this way we avoid the need of a theory to determine numbers of the order 10^{39}.

Let us examine some of the elementary consequences of our general principle. In the first place, we see that the number of protons and neutrons in the universe must be increasing proportionally to t^2. Present-day physics, both theoretically and experimentally, provides no evidence in favour of such an increase, but is much too imperfect to be able to assert that such an increase cannot occur, as it is so small; so there is no need to condemn our theory on this account. Whether the increase is a general property of matter or occurs only in the interior of stars is a subject for future speculation.

A second consequence of our principle is that, if we adopt a scheme of units determined by atomic constants, the gravitational 'constant' must decrease with time, proportionally to t^{-1}. Let us define the gravitational power of a piece of matter to be its mass multiplied by the gravitational constant. We then have that the gravitational power of the universe, and presumably of each spiral nebula, is increasing proportionally to t. This is to some extent equivalent to Milne's cosmology[1], in which the mass remains constant and the gravitational constant increases proportionally to t. Following Milne, we may introduce a new time variable, $\tau = \log t$, and arrange for the laws of mechanics to take their usual form referred to this new time.

To understand the present theory from the point of view of general relativity, we must suppose the element of distance defined by $ds^2 = g_{\mu\nu}dx_\mu dx_\nu$ in the Riemannian geometry to be, not the same as the element of distance in terms of atomic units, but to differ from this by a certain factor. (The former corresponds to Milne's $d\tau$ and the latter to Milne's dt.) This factor must be a scalar function of position, and its gradient must determine the direction of average motion of the matter at any point.

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St. John's College,
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Feb. 5.

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[1] Milne, *Proc. Roy. Soc.*, A, **158**, 324 (1937).

Gamma Rays excited by Capture of Neutrons

LEA's observations and Fermi's pioneer work has shown that many elements may capture a neutron, and emit gamma rays in the process. This phenomenon has been further investigated especially by Rasetti[1], and more recently by Kikuchi[2] and Fleischmann[3], who used polonium-beryllium, deuteron-deuterium and radon-beryllium sources respectively.

We have used radon-beryllium sources, with an experimental arrangement designed to reduce the high background effects of the Geiger counter due to the gamma rays emitted by this type of neutron source, and also to concentrate slow neutrons on the counter. As indicated in the diagram (Fig. 1), a cylindrical block of lead 18 cm. in diameter and 44 cm. in length is sunk into a thick-walled paraffin wax tube closed at the bottom. The radon-beryllium neutron source is placed on the axis of the lead block at a distance of 29 cm. from the top. The neutrons emitted are slowed down by the paraffin wax, diffuse through the lead core, and slow neutrons emerge at the top of the lead block. The efficiency of this arrangement is based on the fact that the mean free path for scattering of slow neutrons is much larger in lead than in paraffin. Gamma ray effects were measured by a thin-walled magnesium counter covered by a thick-walled lead tube and placed in the neutron stream; beta rays and secondary electrons were measured with the same counter uncovered.

The capture radiation from a thick sheet of cadmium (0·4 gm./cm.^{2}) placed below the counter produced 1,700 impulses per minute above the background; the background amounted to 440 impulses per minute with a radon-beryllium source of about 500 mc. The capture radiation of cadmium (and other strongly absorbing elements) is thus a sensitive, and in many respects a very convenient, indicator for slow neutron intensities in our arrangement.

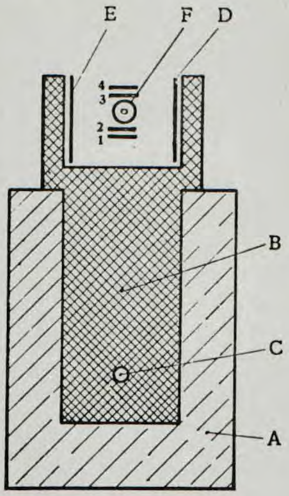

Fig. 1.

A, PARAFFIN WAX TUBE; *B*, LEAD CORE; *C*, RADON-BERYLLIUM SOURCE; *D* AND *E*, BORON SCREENS; *F*, GEIGER-MÜLLER COUNTER; 1, 2, 3, 4, POSITIONS OF THE SAMPLES.

We have used it as an indicator to determine the absorption of slow neutrons in a number of elements. A sample of the element was placed below the counter, a sheet of cadmium inserted between this sample and the counter, and the gamma ray effect measured. This, compared with the gamma ray effects obtained in the absence of the cadmium, and in the absence of the sample, gives the absorption of the sample. The results are shown in Table 1. Our values are not corrected for a slight divergence of the neutron stream, which may account for the fact that most of them are slightly above those of Dunning and Pegram[4], who used the disintegration of lithium as an indicator.

TABLE 1.

Element	Compound	gm./cm.^{2}	Per cent transmitted	Cross-section ($\times 10^{-24}$ cm.^{2})
Cl	CCl_4	1·30	34	52
Co	Co_2O_3	2·87	44	39
Rh	Rh	0·68	51	170
Ag	Ag	1·07	56	97
Cd	Cd	0·0285	50	4,500
Ir	Ir	0·61	46	410
Au	Au	3·14	37	103
Hg	HgO	0·70	50	355

Further, we have compared the gamma ray effect per captured neutron as measured by the counter for a number of strong absorbers of slow neutrons, and the results are given in Table 2. The value for cadmium is arbitrarily fixed at 100.

TABLE 2.

Cl	Co	Rh	Ag	Cd	In	Sm	Gd	Ir	Au	Hg
95	86	82	75	100	94	94	94	74	80	105

The same samples of elements were used to measure both the absorption cross-section and the gamma ray effect, and the values given in column four of Table 1 were then used to compute the relative gamma ray effect per captured neutron. The value for indium includes gamma rays from the induced activity of the 54-minute period. Otherwise the figures include only gamma rays from induced activities of periods shorter than half-hour; longer periods were not appreciably excited in our experiments.

The eleven elements investigated give almost equal effects although their atomic weights range from 35 to 200.

A similar comparison of the gamma rays emitted by elements which are weak absorbers of slow neutrons would, in our opinion, require better data on the elastic scattering of such elements than is at present available. So far, with no element heavier than chlorine have we found evidence to show that the gamma ray effect is appreciably different from 'normal'.

About equal effects might be expected if each element emitted one gamma ray quantum per captured neutron, but other observations do not support this simple interpretation of our result, since they seem to indicate that a larger number of quanta are emitted from the investigated elements.

We obtained some indication of this number by comparing the number of fast electrons ejected backwards from lead by the gamma rays from cadmium which were excited by a slow neutron beam, with the number of beta rays from a very thin silver foil made radioactive by the same neutron beam. Half-value thicknesses in lead were determined for the electrons from lead and for the gamma rays from cadmium. The values obtained indicate that more than seven quanta are emitted from cadmium per captured neutron, but this result requires confirmation by an independent method which is now being attempted.

The fact that chlorine shows a 'normal' gamma ray value indicates that its intense neutron absorption is due to radiative capture that leads to a chlorine isotope of long half-life period which has not yet been detected. Samples of yttrium prepared free from gadolinium by Dr. J. K. Marsh, Old Chemistry Laboratory, Oxford, showed only very weak capture radiation and, in agreement with a measurement of Hevesy[5], a small absorbing cross-section. Thus the widespread view[6], based on earlier measurements, that yttrium has a large capture cross-section for slow neutrons and therefore must transform into an undetected radioactive isotope, does not seem to be justified. Barium also shows a much smaller capture cross-section ($< 10 \times 10^{-24}$ cm.^{2}) than given by earlier measurements[4]. In agreement with Kikuchi[2], we find that boron shows a gamma ray effect of about a twentieth of that of cadmium.

J. H. E. GRIFFITHS.
LEO SZILARD.

Clarendon Laboratory,
University Museum,
Oxford.
Jan. 20.

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[1] Rasetti, *Z. Phys.*, **97**, 64 (1935).

[2] Kikuchi, Husimi and Aoki, *Proc. Phys.-Math. Soc. Japan*, 18, 188 (1936).

[3] Fleischmann, *Z. Phys.*, **100**, 307 (1936).

[4] Dunning, Pegram, Fink and Mitchell, *Phys. Rev.*, **48**, 265 (1935).

[5] Hevesy and Levi, NATURE, **137**, 185 (1936).

[6] Cf. Feather, "Nuclear Physics", p. 183 (1936).

ad Phys ⑩

GAMMA RAYS EXCITED BY CAPTURE OF NEUTRONS

Experiments of Lea and Fermi's pioneer work have shown that many elements may capture a neutron, and emit gamma rays in the process. This phenomenon has been further investigated especially by Rasetti,[1.)] and more recently by Kikuchi[2.)] and Fleischmann,[3.)] who used Po-Be, D-D, and Ra-Be sources respectively. We have used Rn-Be sources with an experimental arrangement designed to reduce the high background effects of the Geiger counter associated with this type of neutron source, and also to concentrate slow neutrons on the counter. With this arrangement we have measured the relative intensities of the gamma rays emitted from a number of elements per captured neutron, and also carried out other measurements in which the capture radiation of Cadmium was used as an indicator of the slow neutron intensity.

As indicated in the diagram, a cylindrical block of lead 18 cm in diameter and 44 cm in length is sunk into a thick walled paraffin wax tube which is closed at the bottom. The neutron source is placed in the axis of the lead block at a distance of 29 cm from the top. The neutrons emitted from the Rn-Be source are slowed down by the paraffin wax, diffuse through the lead core, and slow neutrons emerge at the top of the lead block. The mean free path for scattering of slow neutrons is much larger in lead than in paraffin, and therefore the present arrangement functions in a way rather similar to that in which slow neutrons diffuse through an empty paraffin wax tube. A Geiger-Müller counter was placed above the top of the lead core, and samples of various elements were placed in the neutron stream below or above the counter in the position indicated in the diagram by numbers 1 or 2, and 3 or 4 respectively. Gamma ray effects were measured by a thin walled (.03 gm/cm^2) magnesium counter covered by a thick walled (2 gm/cm^2) lead tube; beta rays and secondary electrons were measured with the same counter uncovered.

The capture radiation from a thick sheet of Cd ($0.4\ gm/cm^2$) placed below the counter in position 1 produced 1700 impulses per minute above the background. The background amounted to 440 impulses per minute ~~above the~~ which is a low value for this type of experiment with a Rn-Be source (about 500 mc). The capture radiation of Cd (and other strongly absorbing elements) is thus a sensitive, and in many respects a very convenient indicator for slow neutron intensities in our arrangement.

We have used it as an indicator to determine the absorption of slow neutrons in a number of elements. A sample of the element was placed below the counter in position 1, a sheet of Cd inserted between this sample and the counter in position 2, and the gamma ray effect measured. This, compared with the gamma ray effects obtained in the absence of the Cd, and in the absence of the sample, gives the absorption of the sample. The results are shown in Table 1. Our values are not corrected for a slight divergence of the neutron stream which may account for the fact that most of them are slightly above those of Dunning and Pegram 4.) who used the disintegration of Lithium as an indicator.

TABLE 1

Element	Compound	g/cm^2	%transmitted	X-section $10^{-24} cm^2$
Cl	CCl_4	1.30	34	52
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Further we have compared the gamma ray effect measured by the counter per captured neutron for a number of strong absorbers of slow neutrons , and the results are given in Table 2. The value for Cd is arbitrarily fixed at 100.

TABLE 2

Cl	Co	Rh	Ag	Cd	In	(In)	Sm	Gd	Ir	Au	Hg
95	86	91	75	100	94	(62)	94	94	74	80	105

The same samples of elements were used to measure both the absorption cross section and the gamma ray effect, and the values given in cloumn 4 of Table 1 were then used to compute the relative gamma ray effect per captured neutron . The value given for In includes gamma rays from the induced activity of the 54 minute period. Otherwise the figures include only gamma rays from induced activities of periods shorter than ½ hour , longer periods were not appreciably excited in our experiments.

The eleven elements investigated give almost equal effects although their atomic weights range from 35 to 200.

About equal effects might be expected if each element emitted one gamma ray quantum per captured neutron, but observations mentioned below do not support this simple interpretation of our result , since they seem to indicate that a large number of quanta are emitted from Cd. Therefore the equal effects shown by the elements investigated deserves some comment which will be given in a more detailed paper.

A similar comparison of the gamma rays emitted by elements which are weak absorbers of slow neutrons would, in our opinion , require better data in the elastic scattering of such elements than is at present available. So far with no element heavier than Cl have we found evidence to show that the gamma ray effect is appreciably different from "normal".

The fact that Cl shows a "normal" gamma ray value indicates that its intense neutron absorption is due to radiative capture and leads to a Cl isotope of a long half life period which has not yet been detected . Samples of Yttrium prepared free from

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Leo Szilard

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January, 1937.

1.) Rasetti. Z.f.Phys. 97,64,(1935).
2.) Kikuchi,Husimi and Aoki. Proc.Phys.-Math. Soc.,Japan. 18,188(193
3.) Fleischmann. Z.f.Phys. 100,307 (1936).
4.) Dunning, Pegram,Fink, and Mitchell. Phys.Rev. 48,265 (1935)

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T. ⑩ D

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1.30 34

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The capture radiation from a thick sheet of Cd (0.4 gm/cm) placed below the counter in position 1 produced 1700 impulses per minute above the background. The background amounted to 440 impulses per minute, which is a relatively low value for this type of experiment with a Rn - Be source (about 500 mc). The capture radiation of Cd (and other strongly absorbing elements) is thus a sensitive, and in many respects a very convenient indicator for slow neutron intensities in our arrangement.

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Table I.

Further we have compared the gamma ray effect measured by the counter per captured neutron for a number of strong absorbers of slow neutrons and the results are given in Table II. The value for Cd is arbitrarily fixed at 100.

<u>Table II.</u>

The eleven elements investigated give almost equal effects although their atomic weights range from 35 to 200.

About equal effects might be expected if each element emitted one gamma ray ~~a~~ quantum per captured neutron but observations mentioned below do not support this simple interpretation of our result, since they seem to indicate that a large number of quanta ~~(of the order of ten)~~ are emitted from Cd. Therefore the equal effects shown by the elements investigated deserves some comment, which will be given in a more detailed paper.

A similar comparison of the gamma rays emitted by elements which are weak absorbers of slow neutrons would, in our opinion, require better data on the elastic scattering of such elements than is at present available. So far with no element heavier than Cl have we found that the gamma ray effect is appreciably different from "normal".

The fact that Cl shows a ~~perfectly~~ normal gamma ray value ~~suggests strongly~~ indicates that its intense neutron absorption is due to radiative capture~~,~~ and leads to a Cl isotope of a long half life period which has not yet been detected.

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LEO SZILARD

Jan 1937

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Au	Au	3.14	37	103	88
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Table II.

Cl	Co	Rh	Ag	Cd	In$^+$	In	Sm	Gd	Ir	Au	Hg.
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* In$^+$. includes γ-rays from the induced activity of the 54 minute period, otherwise the figures include any γ-rays from induced activities of periods shorter than ½ hour. Longer periods were not appreciably excited in our experiments.