Diurnal Variation of Cosmic Rays and Terrestrial Magnetism

Quite recently A. H. Compton[1] and Bennett, Stearns and Compton[2] have secured data showing that the intensity of the softer components of the penetrating radiation increase with magnetic latitude and with the altitude of the sun above the horizon. They suggest that the variation with latitude results from the ionic nature of the ionizing ray. Indeed, this is just what one would conclude from the expansion chamber experiments which show tracks corresponding to ionic energies of 10^9 electron volts and these would be greatly deflected by the earth's magnetic field. It is the purpose of this note to point out that the diurnal variation of the cosmic-ray intensity is a necessary consequence of the newly demonstrated deflectibility of the ionizing particles by the earth's magnetic field.

The observed variation of cosmic-ray intensity with latitude shows that the intensity is quite sensitive to the magnitude and the direction of the earth's magnetic field. Thus since the earth's magnetism is subject to a large diurnal variation we should expect a reflected variation in the cosmic-ray intensity.

We have shown that diamagnetism in the ionized regions of the high atmosphere distorts the earth's magnetic field in much the same way as the solar magnetic field is distorted, except the distortion is much less and is confined pretty much to the sunlit side of the earth. This diurnal distortion decreases the magnetic field above 200 km by 0.1 percent or more in noonday regions so that the cosmic rays (or perhaps, more precisely, the secondary rays) are less deflected and produce locally more intense ionization at low levels. Qualitatively the observed diurnal variation is about what we would infer from the way that the ionization changes with latitude.

Thus it does not seem necessary to suppose that the sun is a weak source of penetrating radiation or that space in the direction of the sun has special properties.

Perhaps, we should point out finally that the asymmetry of the earth's magnetic field will introduce variations of the cosmic-ray intensity with longitude and with the time of year.

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[1] A. H. Compton, Phys. Rev. **41**, 111 (1932).

[2] Bennett, Stearns and Compton, Phys. Rev. **41**, 119 (1932).

The Spin of the Neutron

From some of the recent information reported about neutrons it seems possible to find out whether the neutron has a spin and if so what its value is. In order to do this it is necessary to make several assumptions about the structures of light nuclei: (1) They are built as far as possible out of alpha-particles. (2) The nuclear spin is determined from the spin of its component spins alone. (3) From the evidence that neutrons may be obtained from Li, it is assumed that at least one of the isotopes contains a neutron in its nucleus. (4) The possibilities considered for the spins of the various particles in the nucleus are proton 0, $\frac{1}{2}$; neutron 0, $\frac{1}{2}$, 1; electron 0, $\frac{1}{2}$; alpha-particle 0. The first assumption is one commonly made and is supported by studies on the artificial disintegration of the light elements. The second assumption seems reasonable for the light elements in view of what is known about their nuclear moments. (If orbital moments quantized to integer values are assumed for the nucleus, deductions about whether the nuclear moment should be integer or half integer are not disturbed but those utilizing the actual value are.)

The spin of the free proton is determined from hydrogen to be $\frac{1}{2}$ and that of the extranuclear electron is well known to be also $\frac{1}{2}$ but the possibility of both of these losing their spin in a nucleus should not be overlooked. The various possibilities given above will be divided into two groups for which the proton spin is considered to be 0 and $\frac{1}{2}$ respectively.

As nuclei on which to try these various possibilities the two isotopes of Li, and N^{14} are considered. Curie and Joliot[1] have recently discovered that the highly penetrating radiation emitted from lithium when it is bombarded with alpha-particles from polonium consists of neutrons. They are similar to the particles emitted by Be and B recently dis-

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[1] Curie and Joliot, Nature **130**, 57 (1932).

cussed by Chadwick,[2] though having less energy. It thus seems probable that one of the two isotopes of lithium contains a neutron. Under the above assumptions we have the following possibilities for the structure of Li^6, Li^7 and N^{14}:

Li^6 (*A*) $1\alpha+2p+1e$
(*B*) $1\alpha+1p+1n$
Li^7 (*C*) $1\alpha+3p+2e$
(*D*) $1\alpha+2p+1n+1e$
(*E*) $1\alpha+1p+2n$
N^{14} (*F*) $3\alpha+2p+1e$
(*G*) $3\alpha+1p+1n$.

Let us first consider that the proton has zero spin when it is a part of a complex nucleus. Let us denote the spin of the proton, electron, and neutron by s_p, s_e, and s_n, respectively. The possible resultants may be presented in Table I.

TABLE I.

Nucleus	Case	Structure			$s_e=0$			$s_e=\frac{1}{2}$		
		p	n	e	$s_n=0$	$s_n=\frac{1}{2}$	$s_n=1$	$s_n=0$	$s_n=\frac{1}{2}$	$s_n=1$
Li^6	*A*	2	0	1	0	0	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	B	1	1	0	0	$\frac{1}{2}$	1	0	$\frac{1}{2}$	1
Li^7	*C*	3	0	2	0	0	0	0, 1	0, 1	0, 1
	D	2	1	1	0	$\frac{1}{2}$	1	$\frac{1}{2}$	0, 1	$\frac{1}{2}$, $1\frac{1}{2}$
	E	1	2	0	0	0, 1	0, 2	0	0, 1	0, 2

The Li^7 nucleus is known to have a resultant moment of $1\frac{1}{2}$. This possibility appears only once in the table and to obtain it s_e must be $\frac{1}{2}$ and $s_n=1$. These same conditions however for Li^6, give a resultant of either $\frac{1}{2}$ or 1 and it is known that the resultant moment is 0. This contradiction means that the spin of the nuclear proton must not be 0.

Let us now consider that the proton has spin $\frac{1}{2}$ in the nucleus. The possible resultant spins for Li^6, Li^7, and N^{14}, may be presented in Table II.

Using the facts that the resultant nuclear spins of Li^6, Li^7, and N^{14} are 0, $1\frac{1}{2}$ and 1, respectively, one sees that if $s_n=0$ then s_e must be 0 and hence neither Li^6, Li^7, or N^{14} may contain a neutron. But since we consider the fact that neutrons are observed from lithium to indicate that they are present in the nucleus of either or both Li^6 and Li^7, this is not possible and the neutron must have a spin. If $s_n=1$ then s_e must be 0 and cases *A*, *C*, *E*, and *G* satisfy the requirements. If $s_n=\frac{1}{2}$, then s_e may be either 0 (all cases acceptable) or $\frac{1}{2}$ (*B*, *C*, *E*, and *G* acceptable).

Three possibilities remain:

I $s_p=\frac{1}{2}$, $s_n=\frac{1}{2}$, $s_e=0$
II $s_p=\frac{1}{2}$, $s_n=\frac{1}{2}$, $s_e=\frac{1}{2}$
III $s_p=\frac{1}{2}$, $s_n=1$, $s_e=0$.

If $s_n=\frac{1}{2}$ and $s_e=\frac{1}{2}$ then Li^6 must contain a neutron. If this neutron is the one which is dislodged by bombardment with alpha-particles then either with or without capture of the alpha-particle the products give isotopes which are not known and which in addition belong to a class of which an isotope has never been found to exist, namely with more than twice as many protons as electrons:

$$Li^6+He^4=n_1+B^9$$
$$Li^6+He^4=n_1+Li^5+He^4.$$

Of course there could be complete disintegration but it is doubtful whether this would furnish sufficient energy to eject the neutron. Also if $s_n=\frac{1}{2}$ and $s_e=\frac{1}{2}$, N^{14} must contain a neutron but there is no evidence for this though there is ample evidence that it disintegrates with the emission of a proton when bombarded with alpha-particles. Finally, if $s_e=\frac{1}{2}$ then it must be assumed that its magnetic moment is diminished to about 0.001th the value which it has for an extra-nuclear electron to account for the small size of hyperfine structure separations. This all seems improbable.

Consider the possibility $s_n=1$ and $s_e=0$. There are over fifteen isotopes of various ele-

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[2] J. Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).

TABLE II.

Nucleus	Case	Structure			$s_e=0$			$s_e=\frac{1}{2}$		
		p	n	e	$s_n=0$	$s_n=\frac{1}{2}$	$s_n=1$	$s_n=0$	$s_n=\frac{1}{2}$	$s_n=1$
Li^6	*A*	2	0	1	0, 1	0, 1	0, 1	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$
	B	1	1	0	$\frac{1}{2}$	0, 1	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}$	0, 1	$\frac{1}{2}, 1\frac{1}{2}$
Li^7	*C*	3	0	2	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$
	D	2	1	1	0, 1	$\frac{1}{2}, 1\frac{1}{2}$	0, 1, 2	$\frac{1}{2}, 1\frac{1}{2}$	0, 1, 2	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$
	E	1	2	0	$\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$
N^{14}	*F*	2	0	1	0, 1	0, 1	0, 1	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}, 1\frac{1}{2}$
	G	1	1	0	$\frac{1}{2}$	0, 1	$\frac{1}{2}, 1\frac{1}{2}$	$\frac{1}{2}$	0, 1	$\frac{1}{2}, 1\frac{1}{2}$

ments which have odd mass numbers and odd nuclear moments which are quite certain. If $s_n=1$, then neutrons can exist in the nuclei of any of these only in pairs, which seems to be a peculiar limitation.

The possibility $s_n=\frac{1}{2}$, $s_e=0$, meets with none of these objections as far as is known. In addition it is more satisfying than either of the other two possibilities if one thinks of the neutron as composed of a proton and an electron in some way, since II, which gives both electron and proton a spin of $\frac{1}{2}$ in the nucleus, would require one or the other to lose its spin in the neutron and III, which gives only the proton a spin, would require both to have spin in the neutron.

One may conclude that, under the assumptions mentioned at first, the neutron must have a spin and that the proton must have a spin of $\frac{1}{2}$ in the nucleus. Of the three possibilities which present themselves the case with $s_p=\frac{1}{2}$, $s_n=\frac{1}{2}$, and $s_e=0$ seems most probable.

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Electron Affinity of Hydrogen

From simple Bohr theory one calculates the electron affinity of the hydrogen atom to be 1.69 electron-volts which must be too large in the same way that the ionization potential of helium so calculated is 28.5 electron-volts as compared with the experimental value of 24.47 volts. Pauling[1] thought to improve the calculation of the electron affinity of hydrogen by determining the screening-constant for a two electron system from the Known ionization potential of helium. He however found hydride ion unstable (−0.08 volts). Lately the ionization potentials of Li^+ and Be^{++} have been determined spectroscopically by Edlin and Ericson[2] to be 75.28 and 153.15 electron-volts respectively. It is then possible to find the variation of screening constant (s) with atomic number (Z) and to interpolate S for hydride ion. The empirically determined *electron affinity of hydrogen is found to be* +0.66 *electron-volts.* Bartlett[3] assumes a linear relation between the square root of the ionization potential of He, Li^+, Be^{++} and their atomic numbers and finds by extrapolation +1.4 electron-volts. Hylleraas[4] calculates the electron affinity of hydrogen from wave mechanics to be +0.715 electron-volts.

Atom	S	Ioniz. potential
Bohr	0.2500	
H^-	(0.2780)	(0.66)
He	0.2961	24.47
Li^+	0.3020	75.28
Be^{++}	0.3047	153.15

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August 5, 1932.

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[1] L. Pauling, Phys. Rev. **29**, 285 (1927).

[2] B. Edlin and A. Ericson, Nature **124**, 688 (1929).

[3] J. H. Bartlett, Jr., Nature **125**, 459 (1930).

[4] E. A. Hylleraas, Zeits. f. Physik **65**, 209 (1930).