The present communication represents an extension and generalization to changing magnetic fields in galaxies. Attention is confined to problems of axial symmetry about the axis of z, i.e., to problems in which the electric and magnetic fields E and H show no variation with the θ coordinate.

If one applies Lagrange's equations to the Lagrangian function, L, given in cylindrical coordinates by

$$L=-mc^2(1-r^2\dot{\theta}^2/c^2-\dot{r}^2/c^2-\dot{z}^2/c^2)^{\frac{1}{2}}+er\dot{\theta}U_\theta/c,$$

where the scalar potential ϕ is zero in our problem, and where U_θ is the vector potential and m the rest mass of the particle, it readily follows that:

(1) If a charged particle starts to acquire kinetic energy at $t=0$, and if the magnetic field is zero at $t=0$, then the particle acquires energy continually.
(2) If, at $t=0$, the magnetic field is finite, a sufficient, but by no means necessary, condition for continual gain of energy is that $|E|\geqslant|H|$ for all positions and times.

It can be readily shown that when the magnetic field and kinetic energy T are both zero at $t=0$,

$$\frac{d}{dt}(T+mc^2)^2=e^2\frac{\partial U_\theta^2}{\partial t^2}=e^2\left(\frac{dU_\theta^2}{dt^2}-\dot{r}\frac{\partial U_\theta^2}{\partial r}-\dot{z}\frac{\partial U_\theta^2}{\partial z}\right).$$

Further, it can readily be shown that the terms $(-\dot{r}\partial U_\theta^2/\partial r)$ and $(-\dot{z}\partial U_\theta^2/\partial z)$ are always positive, so that

$$\frac{d}{dt}(T+mc^2)^2\geqslant e^2\frac{dU_\theta^2}{dt^2},$$

and consequently, since T and U_θ are zero at $t=0$,

$$(T^2+2mc^2T)^{\frac{1}{2}}\geqslant eU_\theta.$$

From this result, and neglecting $2mc^2T$ in comparison with T^2, for convenience but not of necessity, it appears that the kinetic energy T acquired by a proton which finds itself at the cylindrical radius r, where the average z component of magnetic field is $\bar{H}_z$ within that radius is such that

$$T\geqslant 150r\bar{H}_z \text{ electron volts.}$$

If $r\sim 25\,000$ light years, as for Andromeda, and $\bar{H}\sim 7\times 10^{-6}$ gauss, $T\sim 2.3\times 10^{19}$ ev.

It also appears that the particle, in its motion, spirals outwards, inwards or remains on a circle, according as $\bar{H}_z>2H_z$, $\bar{H}_z<2H_z$, $\bar{H}_z=2H_z$, respectively, where $\bar{H}_z$ is the average z component within the radius r at which the z component of the magnetic field has the value H_z. If in its journey through places where $\bar{H}_z\neq 2H_z$ the particle reaches a place where $\bar{H}_z=2H_z$, then it will asymptotically approach a circular orbit for that value of r.

A strict application of the foregoing to a case where the growth of the magnetic field has occurred uniformly throughout the life of the universe ($\sim 5\times 10^9$ years) would encounter the difficulty that since the mean life of a cosmic ray as determined by nuclear collisions is of the order 10^8 years, the rays which started to acquire energy at $t=0$ would no longer be with us. The difficulty can be surmounted by assuming that the magnetic field has a period of less than 4×10^8 years, or by considering the case of neutral particles which become ionized and start to acquire energy after the magnetic field has grown to a finite value. The latter problem requires more intricate mathematical considerations which will be dealt with in a later communication.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] W. F. G. Swann, Phys. Rev. **43**, 217 (1933); J. Franklin Inst. **215**, 273 (1933). A simplified version of the original problem is given by the writer in the September, 1954 issue of the *Journal of The Franklin Institute*, and the full details associated with the *present* communication will be published in the November, 1954 issue of that Journal.

Gamma Radiation from the Reactions $Na^{23}+p$

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THERE are three reactions which produce gamma radiation when sodium is bombarded with protons; these are $Na^{23}(p,p'\gamma)Na^{23}$, $Na^{23}(p,\alpha\gamma)Ne^{20}$, and $Na^{23}(p,\gamma)Mg^{24}$. Sodium iodide scintillation detectors have been used to study the gamma rays from these processes at most of the resonances in the range of proton bombarding energy from 0.7–1.5 Mev. The targets were of sodium bromide. Both thin-target and thick-target excitation functions were measured.

The energies of the gamma rays from the inelastic scattering process and from the $(p,\alpha\gamma)$ reactions were found to be 444±5 kev and 1.629±0.008 Mev, respectively, in agreement with other work.[1,2]

The observed capture gamma rays can be related to transitions to the ground state of Mg^{24}, to and from the well-known levels at 1.37 Mev and 4.12 Mev, and to and from the level recently reported by Hausman *et al.*[3] at 4.24 Mev (see Fig. 1). It seems likely that this level decays both to the ground state and to the 1.37-Mev level, since gamma rays of energy 4.24±0.04 Mev and 2.8±0.05 Mev, with relative intensities of about 1 and 0.2, respectively, always occurred together when this mode of decay was observed.

In addition, a gamma ray of energy 3.86±0.04 Mev was definitely observed at one resonance and less definitely at two others. It was found to be in coincidence with gamma rays of energy 1.37 Mev and 7.9 Mev. A possible interpretation is that it arises from a triple cascade transition through a level at 5.23±0.04 Mev. Such a level could be reached in the β decay of Na^{24}.

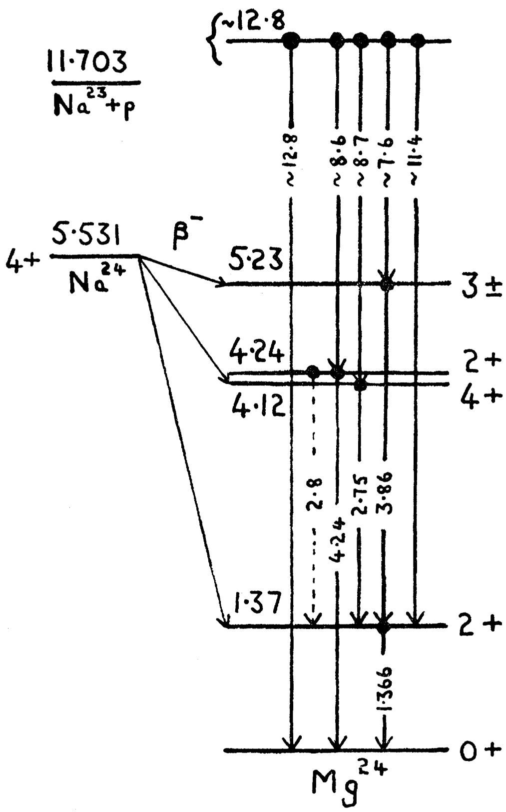

FIG. 1. Proposed energy level scheme for Mg^{24}. Observed gamma rays are shown. Only a few of these occur with appreciable intensity at a given resonance.

Cavanagh and Turner[4,5] have observed a gamma ray from this process having an energy of 3.9 Mev and an intensity of 1 in 2000 disintegrations. It has also been reported by Beghian, Bishop, and Halban,[6] who gives a value of 3.7±0.1 Mev for the energy. There is no evidence from any of the other reactions leading to Mg^{24} to suggest that there is a level at ~3.8 Mev, although such evidence would be expected if the level did in fact exist. The decay scheme of Na^{24} therefore gives some support for the assumption that there is a level in Mg^{24} at 5.23 Mev. The proposed level scheme for this nucleus is shown in Fig. 1.

At the 1.392-Mev resonance, gamma rays were observed which could be interpreted as arising from two parallel cascades, one through the 4.24-Mev level and the other through the 5.23-Mev level. Angular distribution and correlation measurements were made, and it was deduced from these that the 4.24 and 5.23-Mev levels had spins 2 and 3, respectively. From the upper limit of 2×10^{-6} per disintegration set by Beghian *et al.*[6] to the intensity of a ~4.14-Mev gamma ray in the beta decay of Na^{24}, it follows that the beta transition to the

TABLE I. Widths and partial widths in the reactions $Na^{23}+p$. Decays to the ground state are indicated by A, to the first excited state by B, etc. The relative intensities of the weaker modes of decay are indicated in brackets (strongest=1). Γ, Γ_c', Γ_α' and $\Gamma_{pp'}'$ are the total level width and the partial widths for the capture, $(p,\alpha\gamma)$, and (p,p') processes, respectively. The errors in the absolute values of the widths are estimated at ±25 percent.

Bombarding energy Mev	Γ(kev)	Γ_c'(ev)	Mode of decay	Γ_α'(ev)	$\Gamma_{pp'}'$(ev)	J
0.742		...	D, B (0.26)	$\sim0.1\Gamma_c'$	$0.2\Gamma_c'$	1, 2
0.869		13	A, B (0.23)	~1	<0.2	1
0.985	<2	4.6	C, B (0.15)	<0.4	<1.5	3, 4
1.008	5	3		80	140	2+
1.017	6	18	D, B (0.3)	<1	130	1, 2
1.080	<5	1		<4	<16	
1.088	11	<0.8		30	60	2+
1.162	<4	2.7	A, B (0.8)	170	180	1−
1.172	<4	13	A, B (0.5), D (0.7)	<2	9	
1.201	<4	6.4	D, B (0.3)	<6	<5	
1.210	<3	<1		110	130	
1.253	<3	<1		80	100	1+[a]
1.281	9	8	E, B (0.26), D (0.75)	9	1300	
1.319	4	54	B, A (0.2)	<15	<90	
1.328	5	<3		340	1700	
1.358	<4	<3		<2	100	
1.392	<2	20	E, B (0.35), B (0.07)	<4	150	3+
1.415	<1.5	70	C	<22	80	4, 5
1.455	11	10	E, D (1), B (0.1)	50	3000	2−

[a] J. Seed, Phil. Mag. **44**, 921 (1953).

4.24-Mev state is second or higher forbidden, and therefore that if the spin of the 4.24-Mev state is 2 it must have even parity.

The partial widths $\Gamma'=(2J+1)\Gamma$ for the three processes have been estimated from the thick-target excitation curves on the assumption that the main contribution to each level width arises from the re-emission of the incident protons. Spins J are suggested for a number of the resonance levels. These results are shown in Table I.

Other work on the $Na^{23}+p$ reactions has been reported by a number of authors.[1,7–10] A more compregensive description of these experiments and a discussion of the results will be published elsewhere. A brief description of some of this work was given at the Birmingham Nuclear Physics Conference, 1953.

[1] Stelson, Preston, and Goodman, Phys. Rev. **86**, 629 (1952).
[2] Donahue, Jones, McEllistrom, and Richards, Phys. Rev. **89**, 824 (1953).
[3] Hausman, Allen, Arthur, Bender, and McDole, Phys. Rev. **88**, 1296 (1952).
[4] J. F. Turner and P. E. Cavanagh, Phil. Mag. **42**, 636 (1951).
[5] P. E. Cavanagh and J. F. Turner (private communication).
[6] Beghian, Bishop, and Halban, Phys. Rev. **83**, 186 (1951).
[7] Turner, Seagondollar, and Krone, Phys. Rev. **93**, 1035 (1954).
[8] O. H. Turner, Australian J. Phys. **6**, 380 (1953).
[9] H. Casson, Phys. Rev. **89**, 809 (1953).
[10] R. L. Burling, Phys. Rev. **60**, 340 (1941).