field. If an ion is released in a homogeneous magnetic field, it describes a helical path. The angular velocity of the helical motion is ***independent*** of the velocity of the ion and of the direction in which it is released. The time T for a complete revolution is, in round numbers,

$$T=670\ M/H \text{ microseconds.}$$

M is the mass of the ion in atomic weight units and H the field in gauss. For multiple ionization the time of flight is proportionally shorter. For an atomic weight around 150 a field of 100 gauss gives a time of flight of about 1000 microseconds. With a pulsed ion source it should not be too hard to measure this time to about 1/10th of a microsecond. The time interval between different masses is about 7 microseconds per mass unit. If one collects the ions after several revolutions, these time intervals are longer in proportion and a higher accuracy can be obtained.

It is noteworthy that the time of flight increases with the mass M. This means higher relative precision for heavier atoms, for which the methods used so far decrease in accuracy.

Though the time of flight is independent of the velocity of the ions, the dimensions of the apparatus set an upper limit to their speed. For single ions with an energy of V electron volts, the radius R of the helical path is approximately

$$R=145(VM)^{\frac{1}{2}}/H \text{ centimeter.}$$

For a practicable value of R it is necessary to use slow or decelerated ions of less than 100 ev. For multiple ions the radius decreases with the square root of the state of ionization. Too large a value of R may require too high a vacuum.

In addition to the constant time of flight, the helical orbits have a very advantageous focusing property after each complete revolution. All ions from a point source form, after every 360°, a sharp focal line through the source and along the direction of the field. The ion collector can be placed above or below the source, assuming the field H to be vertical. It is intended that the spacing between source and collector can be made large enough to allow the collection of ions which have made several revolutions. A vertical collimation of the ion beam and a controllable vertical deflecting field near the source may give the helical path just the proper pitch.

In the horizontal direction a wide angle can be tolerated, limited only by the dimensions of the magnetic field and its homogeneity. If the radius of the field is R_0 and the radius of the ion path is R, the horizontal half-width of the beam can be $(R_0-R)/R$ radians. Ions outside this angle will hit the wall. Of the magnetic field, only a ring of width $2(R_0-R)$ is used.[1]

The astigmatic focusing in the magnetic field causes the intensity of the various "orders" to go down only with the inverse first power of the number of revolutions. Moreover, the source of ions does not need to be a point. It can be a slit, vertical or horizontal, or an area of arbitrary shape. It is limited mainly by practical geometrical considerations such as difficulty in alignment of the collector, spacing of source and collector, or pulsing or collimating problems. A possible method of pulsing may be to sweep the beam across a slit by means of a modulated or pulsed deflecting field.[2]

Though the actual experiment will present many obstacles, the method described here is so flexible that one expects that such difficulties can be overcome without too much trouble. Moreover, it offers possibilities of expansion which may considerably increase the obtainable precision for measuring masses of heavy atoms. It may be very hard to use this method for absolute measurements. Relative measurements of greatly different masses may not be easy either, because their paths in the field can be very different. For relative masses of heavy elements the time-of-flight method looks most promising. Only after we have finished preliminary experiments, which are now being set up in the simplest possible way, shall we know with some certainty what the limitations of the proposed technique are.

* Research work done at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

1 The focusing at 180° is of no use for our purpose. This is only a focusing in space and not in time.

2 The picture so far is that of a beam of slow ions describing a helix for which the pitch is much smaller than the radius. For fast ions it may be necessary to have them describe a helix with a pitch much larger than the radius. The field inside a long solenoid or inside a ring solenoid may be suitable for such a case. If, however, the method turns out to be worth while at all, the best way to handle faster ions is most likely the construction of an apparatus with a large radius.

The Abundance and Temperature of Methane in the Earth's Atmosphere

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THE presence of methane in the earth's atmosphere has now been definitely established on the basis of recent spectroscopic evidence.[1] From an analysis of equivalent widths of the lines of the P and R branches of the $2\nu_3$ band at 1.666μ, the writers have obtained estimates both of the abundance of methane and of its temperature in the earth's atmosphere.

The equivalent width of an unsaturated absorption line depends linearly on the number of molecules per unit cross section of the absorbing column, on the theoretical strength, and on the Boltzmann factor. If the theoretical line strengths were accurately known, this relationship could be employed to calculate both the abundance and the temperature from the observed line intensities. In the absence of accurate theoretical strengths, we have compared the atmospheric methane intensities with those produced in the laboratory by the use of an incandescent lamp as a source, together with an absorption cell containing a known quantity of methane at a 25-cm pressure and room temperature.

The mass abundance of methane turns out to be 1.2 parts in a million of the earth's atmosphere. The average temperature of the atmospheric column in which the methane absorption took place is −37°C. The observations on which the foregoing results are based were obtained on March 28, 1948, between 22^h 05^m and 22^h 53^m U.T., with the sun at an average altitude of 14°34′.

The calculated temperature of −37°C is a reasonable value, being that normally found at a height of about 8 km.[2] Pending further study, nothing definite can be stated as to the lateral and vertical distribution of the methane in the earth's atmosphere. The indicated average height of 8 km is reasonable for the relatively light CH_4 molecule. Analysis of tracings made with the sun at various altitudes should provide further information on the vertical distribution.

[1] Marcel V. Migeotte, Phys. Rev. **73**, 519 (1948); McMath, Mohler, and Goldberg, *ibid.* 1203 (1948).
[2] *Smithsonian Physical Tables* (1934), p. 559.

Plasma Oscillations as a Cause of Acceleration of Cosmic-Ray Particles

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ONE of the earliest hypotheses to explain the high energies of cosmic rays postulated weak interstellar electric fields, extending over enormous distances in space. These fields cannot be static because the known concentration of highly mobile ions in space rapidly produces neutralization. On the other hand, if an appreciable number of high energy particles are to be obtained from small oscillatory or fluctuating fields, it seems essential that there be present systematic effects producing cumulative energy transfers of the same sign over a long period of time. We wish to suggest here that plasma oscillations of ion clouds in intra-galactic space can provide such a mechanism of cumulative energy transfers.

About 15 percent of the volume of intra-galactic space is occupied by dust clouds, in which the ion density is of the order of 1 per cm^3. Like any other ion gas, this system constitutes a plasma[1] which can execute longitudinal electronic oscillations of angular frequency,[2]

$$\omega^2=(4\pi n_0\epsilon^2/m)+(3kT/m)(2\pi/\lambda)^2,$$

where n_0 is the mean electron density, T the electron temperature, and λ the wave-length. The electron temperature in these gases usually corresponds to a mean kinetic energy of a few ev.

It is found, experimentally[1] and theoretically,[3] that plasma oscillations are readily excited by special groups of electrons which have appreciably more than the mean thermal kinetic energy. To excite the interstellar plasma, one requires electrons of about 5 ev, or more, which can be provided by photo-ionization, and perhaps also by emission of streams of charge from hot stars.

Under the influence of a plasma oscillation of small amplitude, most particles will merely experience correspondingly small oscillatory changes of velocity. A particle which happens to be moving with a velocity close to the phase velocity of the wave, however, can be trapped in the trough of the potential, so that it oscillates about a mean speed equal to that of the wave. If the phase velocity should for any reason increase very gradually in the direction of propagation, this particle would tend to remain trapped, and thus would oscillate about an ever-increasing wave velocity. Inspection of the formula for the plasma frequency shows that such an increase of phase velocity is obtained whenever a wave enters a region of increasing ion density. In fact, as n_0 approaches $(m\omega^2/4\pi\epsilon^2)$, the phase velocity grows without limit, thus providing, in principle at least, a mechanism for accelerating particles to arbitrarily high energies. At some point near the above critical density, however, the particle ceases to be trapped, because its mass eventually becomes so great that the electric fields in the wave can no longer supply the mean acceleration needed to match the increase in phase velocity. The maximum energy attainable is determined by the wave amplitude, and this depends on the balance of excitation and damping processes which we hope to investigate in detail.

An important question is whether enough energy can be fed into plasma oscillations to maintain the known flux of cosmic-ray energy. The mean energy density in cosmic rays[4] is about one-fifth that of starlight[5] in interstellar space. If there is a small galactic magnetic field,[6,7] however, as has been suggested on other grounds, each cosmic-ray particle could move in a large orbit making as many as 10,000 revolutions before being absorbed, so that, to maintain the observed flux of cosmic rays, it would be necessary to supply only about 2×10^{-5} of the energy in starlight. It is fairly likely[8] that as much as 10^{-3} of the total energy in starlight goes into photo-ionization; hence this source alone may be adequate.

The final energy spectrum would depend, first, on the details of the acceleration process, and second, on the subsequent degradation in interstellar space.

[1] I. Langmuir, Proc. Nat. Sci. **14**, 627 (1928).
[2] J. J. Thomson, *Conduction of Electricity in Gases* (Cambridge University Press, Teddington), p. 353.
[3] D. Bohm and E. P. Gross, Phys. Rev. (to be published).
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[8] L. Spitzer (private communication).

An Investigation of Samarium and Gadolinium by the Photographic Method*

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MÄDER[1] and Taylor[2] reported that long-range particles were emitted by Sm and suspected that these were protons. However, Cuer and Lattes[3] showed that these were not unique to Sm but appeared also from Nd in each instance with a track length corresponding to Po α-particles. They therefore suggested Po contamination as a source of long-range alphas.