the fact that during the time period Δt of about 10^2 sec. (which is set by the rate of expansion), about one-half of original particles were combined into deuterons and heavier nuclei. Thus we write:

$$v\Delta t n\sigma \cong 1 \tag{5}$$

where $v = 5\cdot 10^8$ cm/sec. is the thermal velocity of neutrons at 10^9 °K, n is the particle density, and $\sigma \cong 10^{-29}$ cm^2 the capture cross section of fast neutrons in hydrogen. This gives us $n \cong 10^{18}$ cm^{-3} and $\rho_{\mathrm{mat.}}{}^{\circ} \cong 10^{-6}$ g/cm^3 substantiating our previous assumption that matter density was negligibly small compared with the radiation density. (Thus we have $\rho_{\mathrm{mat.}}{}^{\circ}\cdot\Delta t \cong 10^{-4}$ g$\cdot$cm$^{-3}\cdot$sec. and not 10^{+4} g$\cdot$cm^{-3} sec. as was given incorrectly in the previous paper[2] because of a numerical error in the calculations.)

Since $\rho_{\mathrm{rad.}} \sim t^{-2}$ whereas $\rho_{\mathrm{mat.}} \sim t^{-\frac{3}{2}}$ the difference by a factor of 10^6 which existed at the time 10^9 sec. must have vanished when the age of the universe was $10^2\cdot(10^6)^2 = 10^{14}$ sec. $\cong 10^7$ years. At that time the density of matter and the density of radiation were both equal to $[(10^6)^2]^{-2} = 10^{-24}$ g/cm^3. The temperature at that epoch must have been of the order $10^9/10^6 \cong 10^3$ °K.

The epoch when the radiation density fell below the density of matter has an important cosmogonical significance since it is only at that time that the Jeans principle of "gravitational instability"[3] could begin to work. In fact, we would expect that as soon as the matter took over the principal role, the previously homogeneous gaseous substance began to show the tendency of breaking up into separate clouds which were later pulled apart by the progressive expansion of the space. The density of these individual gas clouds must have been approximately the same as the density of the universe at the moment of separation, i.e., 10^{-24} g/cm^3. The size of the clouds was determined by the condition that the gravitational potential on their surface was equal to the kinetic energy of the gas particles. Thus we have:

$$\frac{3}{2}kT = \frac{4}{3}\pi R^3\rho\frac{Gm_H}{R} = \frac{4\pi G m_H \rho}{3}R^2. \tag{6}$$

With $T \cong 10^3$ and $\rho \cong 10^{-24}$ this gives $R \cong 10^{21}$cm $\cong 10^3$ light years.

The fact that the above-calculated density and radii correspond closely to the observed values for the stellar galaxies strongly suggests that we have here a correct picture of galactic formation. According to this picture the galaxies were formed when the universe was 10^7 years old, and were originally entirely gaseous. This may explain their regular shapes, resembling those of the rotating gaseous bodies, which must have been retained even after all their diffused material was used up in the process of star formation (as, for example, in the elliptic galaxies which consist entirely of stars belonging to the population II).[4]

It may also be remarked that the calculated temperature corresponding to the formation of individual galaxies from the previously uniform mixture of matter and radiation, is close to the condensation points of many chemical elements. Thus we must conclude that some time before or soon after the formation of gaseous galaxies their material separated into the gaseous and the condensed (dusty) phase. The dust particles, being originally uniformly distributed through the entire cloud, were later collected into smaller condensations by the radiation pressure in the sense of the Spitzer-Whipple theory of star formation.[5] In fact, although there were no stars yet, there was still plenty of high intensity radiation which remained from the original stage of expanding universe when the radiation, and not the matter, ruled the things.

In conclusion I must express my gratitude to my astronomical friends, Dr. W. Baade, Dr. E. Hubble, Dr. R. Minkowski, and Dr. M. Schwartzschield for the stimulating discussion of the above topics.

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Pressure Broadening in Ammonia at Centimeter Wave-Lengths*

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THE intensities and shapes of microwave absorption lines in gases have been successfully correlated with the Van Vleck-Weisskopf[1] modification of the Lorentz impact-broadening theory. The absorption in the long wave-length tails of the ammonia inversion lines offers a severe test of this theory. Precise measurements of this absorption have been completed at wave-lengths 4.43 cm and 3.20 cm in the pressure range 0.1 to 7 atmospheres. These results are plotted in Fig. 1, together with the absorption coefficients computed by numerically summing the Van Vleck-Weisskopf expression over the rotational states, using the measured Bohr frequencies,[2] and a linear pressure variation of the measured half-widths.[2]

The discrepancy between theory and experiment is most severe at the higher pressures, but exceeds the measurement errors at pressures as low as 10 cm of mercury. The discrepancies are apparently inherent in the impact theory

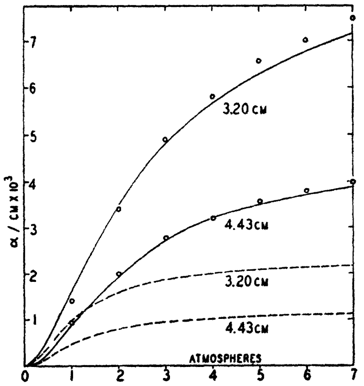

FIG. 1. Free-space absorption coefficient of ammonia at 20°C *vs.* pressure. Solid lines are experimental. Dashed lines are computed with impact theory. Circles are computed as discussed in text.

and cannot be removed by acceptable changes in the parameters.

At very high pressures, not collisions, but intermolecular perturbations, should be used in considering spectral line shapes, and a statistical type of theory should be employed. A crude form of this theory has been devised. The long-range perturbations partially developed by Margenau and Warren[3] suggested averaged perturbations that led to an expression for a statistical absorption coefficient α_s. This α_s differed from the Van Vleck-Weisskopf absorption coefficient α_i only in the shape factor term. The dispersion form in α_i was replaced by a triangular form in α_s.

The line widths in the expression for α_s were estimated from the r.m.s. perturbations, using intermolecular distances equal to the radius of the volume per molecule sphere.

At intermediate pressures the actual line shapes should depend on both statistical and impact processes. The behavior of the impact theory expression when a finite collision duration was introduced together with the assumption that the statistical processes are of importance only when the molecules are closer than the collision distance, suggested that in general the absorption coefficient at any pressure might be written as

$$\alpha = \alpha_i \exp(-ap) + \alpha_s[1 - \exp(-ap)];$$

(ap) was taken to be the ratio of the volume of the collision sphere to the volume per molecule.

The absorption computed in this manner shows no substantial improvement over the impact theory itself, unless the Bohr frequencies used in α_s, and in α_s only, vanish. The circles in Fig. 1 are calculated on this basis. It should be pointed out that none of the parameters used in this computation were adjusted to fit the observed absorption. While calculations have not been carried out in detail, the above theory appears to be in agreement with published observations at shorter wave-lengths.[2, 4, 5, 6]

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On the Use of Nuclear Plates in a Magnetic Field

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SINCE present nuclear plate techniques do not allow direct determination of the sign of particles investigated and individual mass measurements are not very accurate magnetic deflection methods assume considerable importance in the study of cosmic rays. Powell and Rosenblum[1] have proposed that if two parallel emulsion surfaces separated by an air gap are placed perpendicular to a magnetic field, the curvature of a particle's path in air can be obtained from the tracks in the emulsions on either side. We have been using a similar arrangement, differing in several particulars from their method, to determine meson masses at balloon altitudes. Under Pb absorbers we have, in collaboration with J. J. Lord, obtained on our plates meson densities great enough to make measurements on such flights practicable.

In viewing the plates after development, accurate measurements can be made only if the two emulsions are exactly juxtaposed. With ordinary commercial plates, this involves viewing through the glass backing of 1 mm thickness, so that high magnification is impossible with refracting microscopes. Powell has therefore had to use a specially constructed reflecting microscope[2] with a large working distance. In our experiments, we have re-coated the original emulsions on very thin glass plates (150 microns and even down to 50 microns). Besides enabling the use of an ordinary microscope, this method has the additional advantage that if thin plates are coated with emulsion on both sides, several such plates separated by air gaps can be stacked as a "sandwich," and more than one curvature measurement made on the same particle as it crosses successive air gaps. Emulsions coated on thin plates, or on acetate film-backing, will be commercially obtainable in the near future.

The magnetic deflection can be measured by projecting as a straight line the last segment of a track as it leaves the top plate, and determining the distance from this line to the point at which the particle enters the lower emulsion. An independent deflection measurement is obtained by similarly projecting back the first segment of the lower track. Scattering very near the surface may introduce uncertainty in the direction of the projected line which would result in an error in the measured deflection proportional to the path length in air. Since, however, the magnetic curvature produces a deflection proportional to the square of the path length, a greater air gap will reduce the percentage error. Our air gap is 2000 microns wide. For a path length of 10,000 microns in air and our field of 12,500 gauss, the theoretical deflection of a 200 m_e meson of energy 4.5 Mev is 625 microns; for 1.2 Mev, 1250 microns, etc. Events with path length longer than this can readily be recorded, the only limit being the correct matching of tracks in the two emulsions caused by the same particle. The direction of an emergent track and its "dip angle" with the plane of the emulsion are found, and tracks in the lower emulsion in the region where the particle might be expected to strike are noted. We are simplifying this procedure by the use of a projection microscope, a tilting stage to measure dip angles, and a magnifying pantagraph attached to the stage with which the location and orientation of tracks can be traced on a large sheet of paper. Matching is checked by the equality of (a) the two deflection measurements obtained by projecting the upper and lower tracks, respectively, as indicated above; (b) the angles of dip, and (c) the grain densities, above and below. With proton tracks obtained by cyclotron bombardment and with plates exposed on balloon flights we are able to get good matching of tracks between the two emulsions.

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