INTRINSIC PROPERTIES OF LIGHT AND CORPUSCLES FROM DISTANT SOURCES

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Spectra of distant nebulae, compared with those of neighboring nebulae, are shifted toward the red by amounts which increase with the distance which the light has traveled. This fact indicates that we are confronted with a phenomenon which involves history on a large scale, history either of the universe as a whole, or history of some of its individual parts.

Scientifically speaking, *history means the change in time of dimensionless ratios of significant physical quantities.* Thus, on the relativistic interpretation of the redshift of light from nebulae the dimensionless ratio D/d between two lengths changes (increases) in time. Appropriate choices for these two lengths are Bohr's characteristic length $d = h^2/4\pi^2me^2$ as a supposedly fixed terrestrial measuring stick, and $D = V^{1/3}$ where V is the volume which on the average contains one extragalactic nebula. However, many other interpretations of the redshift are possible. The assumption that history must be operative clearly suggests the necessity of an investigation of *all* dimensionless ratios between significant physical quantities. Only after this investigation has been completed will a final understanding of the redshift and other cosmic phenomena be possible.

The following discussion will be concerned with the behavior of the most trivial dimensionless ratios only. A more general program may be outlined, but so far essential data for its realization are lacking.

A. *Nebular Light and Terrestrial Light.*—We shall designate one and the same property for nebular light and terrestrial light with p_N and p_T, respectively. The first step in our program consists in procuring data which will enable us to decide whether or not for a given property p the dimensionless ratio p_N/p_T is equal to unity or not.

For instance, we may put $p_N = c_N$ and $p_T = c_T$ where c_N and c_T are the velocities of nebular light and terrestrial light, respectively, as measured simultaneously at the time of their arrival. Since no direct measurements are available we are forced to accept the values of c_N obtained from the astronomical aberration as a legitimate substitute. Also, c_T in the actual case refers to light from nearby stars instead of terrestrial light directly.

The aberration of light from nebulae relative to the aberration of light from stars was measured by Strömberg and van Biesbroeck. Strömberg[1] has determined the positions of nebulae in the Ursa Major I cluster relative to the surrounding star field in the course of a year. The distance of the

Ursa Major I cluster is of the order of 72×10^6 light-years. Strömberg found that for light from these nebulae

$$c_N/c_T = 1 \pm 0.002. \quad (1)$$

This result indicates that if the redshift from nebulae is in any way related to a change of the velocity of light in time, this change can become apparent only if c_N is measured relative to some standard other than the velocity of terrestrial light. This suggests that we investigate, as functions of time, ratios of the type c/v where v is any significant prototype of a velocity other than c_T. For instance we might choose $v = 2\pi e^2/h$, where v is the "velocity" of an electron in the first "orbit" of a hydrogen atom. Such a dependence of c/v on time might exist if the physical properties of the universe as a whole were subject to history. Although a few experiments have been carried out with some bearing on the above problem, no direct data are available from which one might deduce the behavior of c/v over long intervals of time. We therefore drop this matter for the present.

Our next step calls for a comparison of the interaction with matter of nebular light and terrestrial light.

We *define* the wave-length λ of a monochromatic beam of light by the angle Θ which the diffracted beam forms with the original beam of normal incidence on a plane grating whose spacing is Δ. The definition equation is

$$\lambda = \Delta \sin \Theta. \quad (2)$$

Assuming that Δ/d is independent of time, wave-lengths, through the observation of diffraction patterns, are measured in terms of the fundamental atomic length $d = h^2/4\pi^2 me^2$. The frequency ν is not measured but is introduced by *definition* as $\nu = c/\lambda$. Absorption measurements and the photoelectric effect show that light of the wave-length λ acts in many ways as if it were composed of photons characterized by individual energies $\epsilon = h\nu = hc/\lambda$, where Planck's constant h is presumed to be a universal constant. If this is correct then we should have $h_N/h_T = 1$. Observations to test this point have been made by W. S. Adams and M. L. Humason.[2] These observers have determined the redshift relative to a terrestrial source of light from the extragalactic nebula N. G. C. 4151 both with a grating and a prism spectrograph. The refraction measurements yielded an average apparent velocity of recession $\bar{v}_R = 958$ km./sec., whereas the grating gave $\bar{v}_G = 962$ km./sec. Assuming that only an insignificant part of v is due to the peculiar motion of the nebula it follows from these observations that

$$(hc)_N/(hc)_T = 1 \pm 0.02. \quad (3)$$

In combination with (1) we obtain

$$h_N/h_T = 1 \pm 0.02 \qquad (4)$$

and we may conclude from (1) and (4) that nebular light and terrestrial light possess intrinsically identical physical properties.

In view of the fact that the nebula used in the above observations might accidentally have a peculiar motion with a large component of recession it will be advisable to repeat the observation with some more distant nebula and to use an absorption test (rare earth filter) instead of the refraction test. If this test gives the same result as the one made by Adams and Humason we will have ascertained that nebular light at the time of arrival has intrinsically the same properties as terrestrial light. Assuming this to be correct, the existence of a redshift simply means that certain characteristic features, such as maxima and minima of intensity, or emission and absorption bands in the spectra of distant nebulae appear to be displaced toward the red as compared with what we think to be *comparable features* in the spectrum of a nearby nebula or in the spectra of appropriately chosen stars and terrestrial sources. Continuing our scrutiny of apparently trivial facts, the question then arises as to what we mean by comparable features. The analysis of this question which leads to the investigation of a number of fundamental dimensionless ratios will be given in another paper.

Before abandoning this discussion of the intrinsic properties of light I sketch briefly a related problem which may find its solution through astronomical observations. Certain effects have recently come to our knowledge which suggest that the differential equations governing the propagation of light through empty space are not strictly linear. *Non-linearity* of these equations results in a *dependence* of the *velocity of light on frequency*. One reason for the existence of slight deviations from the superposition principle of light lies in the potential possibility of the formation of pairs of positive and negative electrons by interacting photons. This interaction necessitates a generalization of Maxwell's field equations through the introduction of non-linear terms in the field strengths.[5] As a result, light traveling through space which is free of matter but filled with radiation will have a velocity depending on its frequency. In addition similar effects arise from the gravitational interaction of light with light and matter. Although the effects to be expected are in all probability small the possibility of an experimental test may be kept in mind.

An obvious way of investigating effects of the kind mentioned lies in the observation of light signals of different frequency which have traveled through space for a long time. If we knew of any signals which have started *simultaneously* from a very distant source the dependence of the velocity on frequency could perhaps be demonstrated by checking up on the times of arrival of these signals. A unique case to perform this test is afforded by the observation of distant nova outbursts. For such an outburst we may safely assume that photons in the various emission lines of, say, hydrogen have started out simultaneously on their long journey. We must therefore attempt to determine whether or not the intervals in which the different hydrogen lines flare up in the spectrum of a distant super-nova are zero or not. With the present telescopic equipment it is probably possible to find super-novae to distances as great as 10^8 light-years. With reasonable luck it should be possible to detect differences in the time of arrival of various emission lines amounting to as little as a few days. Observations of this kind will therefore enable us in the most favorable cases to determine the ratio of the velocity of violet light to that of red light traveling through internebular space with a relative accuracy of 10^{-10}.

There already are available some data which might have a bearing on our problem. These data refer to a difficulty which has arisen with respect to the absolute magnitudes and the shape of the light curves of common novae in the Andromeda nebula (Messier 31). About one hundred novae have been found in this galaxy, a number which would seem sufficiently large to constitute a fair collection and to make possible a statistical comparison with the characteristics of galactic novae. This comparison results in two serious discrepancies.

In the first place no common nova in M31 has been observed whose absolute magnitude is brighter than $M = -6.7$. Galactic novae on the other hand often are as bright as $M = -8$ or even $M = -9$. This discrepancy was pointed out to me by Dr. W. Baade of the Mt. Wilson Observatory.

In the second place the light curves of the novae in M31 are on the average considerably flattened as compared with the light curves of similar galactic novae. In particular, the familiar flash or peak which forms the maximum of the light curves of many galactic novae has apparently never been exhibited by any of the novae in M31.

Both of these discrepancies could readily be understood if the velocity of red light and violet light differed by about 10^{-3} to 10^{-2} km./sec.

I have also tried to check up on the light curves of Cepheid variables in nebulae. Extragalactic variables of a given period should have flatter light curves than galactic variables of the same period if the velocity of light depends on frequency as strongly as conjectured above. The data available at the present unfortunately are not accurate enough to test this point.

Another startling fact was observed by Sinclair Smith[3] of the Mt. Wilson Observatory in the spectrum of the recent super-nova in N. G. C. 4273, a member nebula of the Virgo cluster. The spectrum of this nova, contrary to all expectations, did not contain any emission lines in the ultra-violet region between $\lambda = 3100$ Å and $\lambda = 3600$ Å. In fact the intensity of light in this region which might be ascribed to the super-nova is indistinguishable from zero. This fact again can be explained on the assumption that the ultra-violet light from the super-nova mentioned did not arrive simultaneously with the visible light and that it hence was missed. Alternative explanations, however, are still possible. It will be of great interest to discover super-novae in as early stages as possible and to carefully analyze their spectra.

Provided that cosmic rays originate in novae[4] the study of fluctuations in the intensity of these rays will be of particular interest in regard to the problems formulated in this paper. So far, however, the available data are insufficient to draw any definite conclusions.

B. *Corpuscular Rays.*—Common novae, super-novae, Wolf-Rayet stars, etc., eject into interstellar space energetic corpuscular rays of all descriptions. On the other hand, investigations of the polar and the non-polar aurora, as well as the cosmic ray phenomena, indicate that corpuscular rays are continually impinging on the earth's atmosphere from extraterrestrial regions. To correlate these phenomena with the happenings on unstable stellar objects is very suggestive. It is also suggestive to extend the inquiry proposed in this paper from photons to corpuscular rays and to ask whether or not extraterrestrial corpuscles exhibit the same intrinsic properties as terrestrial corpuscles. To answer this question one must investigate dimensionless ratios of the type p_N/p_T, where $p = e, m, \mu$, etc., are the charge, mass, characteristic wave-length, magnetic moment of a corpuscle. Little evidence is available at the present which would enable us to determine any of the significant ratios p_N/p_T. It will be well, however, to keep in mind the eventuality of values $p_N/p_T \neq 1$ for the interpretation of cosmic ray phenomena in order to prove or disprove the so far tacitly made assumption of the *uniformity* of all happenings in the observable parts of the universe.

The program submitted in this paper was outlined several years ago and was discussed on various occasions with those astronomers at the Mt. Wilson Observatory who have made the investigation of distant nebulae their specialty. I am particularly indebted to Drs. W. Baade, E. Hubble and M. L. Humason for coöperating in the attempt to test some of the points of this program.

1 G. Strömberg, *Pub. Astr. Soc. Pac.*, **43**, 266 (1931).

2 W. S. Adams and M. L. Humason, *Pub. Astr. Soc. Pac.*, **48**, 107 (1936).

3 I am indebted to Dr. Sinclair Smith for private communication of his data.

4 See W. Baade and F. Zwicky, these PROCEEDINGS, **20**, 259 (1934).

5 Euler and Kockel, *Naturwiss.*, **23**, 246 (1935).