General Course of Evolutionary Process

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The general course of the evolutionary processes as applied to the principal classes of celestial bodies is thought to be fairly well known. With very few exceptions astronomers are agreed as to the main trend of this order, but this must not be interpreted to mean that there are no outstanding differences of opinion. There are, in fact, some items of knowledge which seem to run counter to every order of evolution that has been proposed.

The large irregular nebulae, such as the great nebula in Orion, the Trifid nebula, and the background of nebulosity which embraces a large part of the constellation of Orion, are thought to represent the earliest form of inorganic life known to us. The material appears to be in a chaotic state. There is no suggestion of order or system. The spectroscope shows that in many cases the substance consists of glowing gases or vapors; but whether they are glowing from the incandescence resulting from high temperature, or electrical condition, or otherwise, is unknown, though heat origin of their light is the simplest hypothesis now available. Whether such nebulae are originally hot or cold, we must believe that they are endowed with gravitational power, and that their molecules or particles are, or will ultimately be, in motion. It will happen that there are regions of greater density, or nuclei, here and there throughout the structure which will act as centers of condensation, drawing surrounding materials into combination with them. The processes of growth from nuclei originally small to volumes and masses ultimately stupendous must be slow at first, relatively more rapid after the masses have grown to moderate dimensions and the supplies of outlying materials are still plentiful, and again slow after the supplies shall have been largely exhausted. By virtue of motions prevailing within the original nebular structure, or because of inrushing materials which strike the central masses, not centrally but obliquely, low rotations of the condensed nebulous masses will occur. Stupendous quantities of heat will be generated in the building−up process. This heat will radiate rapidly into space because the gaseous masses are highly rarefied and their radiating surfaces are large in proportion to the masses. With loss of heat the nebulous masses will contract in volume and gradually assume forms more and more spherical. When the forms become approximately spherical, the first stage of stellar life may be said to have been reached.

It was Herschel's belief that by processes of condensation, following the loss of heat by radiation into surrounding space, formless nebulae gravitated into nebula of smaller and smaller volumes until finally the planetary form was reached, and that planetaries were the ancestors of stars in general. That the planetaries do develop into stars, we have every reason to believe; but that all nebulae, or relatively many nebulae, pass through the planetary stage, or that many of our stars have developed from planetaries, we shall later find good reason for doubting. The probabilities are immensely stronger that the stars in general have been formed directly from the irregular nebulae, without the intervention of the planetaries. The planetary nebula seem to be exceptional cases, but to this point we shall return later.

It is quite possible, and even probable, that gaseous masses have not in all cases passed directly to the stellar state. The materials in a gaseous nebula may be so highly attenuated, or be distributed so irregularly throughout a vast volume of space, that they will condense into solids, small meteoric particles for example, before they combine to form stars. Such masses or clouds of non−shining or invisible matter are thought to exist in considerable profusion within the stellar system. The nebulosity connected more or less closely with the brighter Pleiades stars may be a case in illustration. Slipher has recently found that the spectra of two small regions observed in this nebula are continuous, with absorption lines of hydrogen and helium. This spectrum is apparently the same as that of the bright Pleiades stars. Slipher's interpretation is that the nebula is not shining by its own light, but is reflecting to us the light of the Pleiades stars. That this material will eventually be drawn into the stars already existing in the neighborhood, or be condensed into new centers and form other stars, we can scarcely doubt. The condensation of such materials to form stars large enough to be seen from the great distance of the Pleiades cluster must generate heat in the process, and cause these stars in their earliest youth to be substantially as hot as other stars formed directly from gaseous materials. It is possible, also, that the spiral nebulae will develop into stars, perhaps each such object into many, or some of the larger ones into multitudes, of stars.

Let us attempt to visualize the conditions which we think exist in a newly−formed star of average mass. It should be essentially spherical, with surface fairly sharply defined. Our Sun has average specific gravity of 1.4, as compared with that of water. The average density of the very young star must certainly be vastly lower; perhaps no greater than the density of our atmosphere at the Earth's surface; it may even be considerably lower than this estimate. The diameter of our Sun is 1,400,000 kilometers. The diameter of the average young star may be ten or twenty or forty times as great. The central volume or core of the star is undoubtedly a great deal denser than the surface strata, on account of pressure due to the star's own gravitational forces. The conditions in the outer strata should bear some resemblance to those existing in the gaseous nebula. The star may or may not have a corona closely or remotely similar to our Sun's corona. The deep interior of the star must be very hot, though not nearly so hot as the interiors of older stars; but the surface strata of the young star should be remarkably hot; for, being composed of highly attenuated gases, any lowering of the temperature by radiation into surrounding space will be compensated promptly through the medium of highly−heated convection currents which can travel more rapidly from the interior to the surface than in the case of stars in middle or old age. Even though the star, as observed in our most powerful telescopes, is a point of light, without apparent diameter, its outer strata should supply some bright lines in the spectrum, because these strata project out beyond what we may call the core of the star and themselves act as sources of light. The spectrum should, therefore, consist of some of the bright lines which were observed in the nebular spectrum, these proceeding from the outer strata of the star; and of a continuous spectrum made up of radiations proceeding from the deeper strata or core of the star, in which a few dark lines may be introduced by the absorption from those parts of the outer gaseous strata which lie between us and the core.

A few hundred stellar spectra resembling this description are well known, discovered mostly at the Harvard Observatory. Their details differ greatly, but they have certain features in common. The bright lines of helium are extremely rare in stars, but they have been observed in a few stellar spectra. The bright lines of nebulium have never been observed in a true star: they and the radiations in the ultra−violet known as at 3726A, seem to be confined to the nebular state; and the absorption lines of nebulium have never been observed in any spectrum. As soon as the stellar state is reached nebulium is no longer in evidence. Stellar spectra containing bright lines seem always to include hydrogen bright lines. This is as we should expect; hydrogen is the lightest known gas, and it is probably the substance which can best exist in the outer strata of stars in general. The extensive outer strata of very young stars seem to be composed largely of hydrogen, though other elements are in some cases present, as indicated by the weaker bright lines in a few cases. This preference of hydrogen for the outermost strata is illustrated by several very interesting observations of the nebulae. The nebulium lines are relatively strong in the central denser parts of the Orion and Trifid nebulae, but the hydrogen bright−lines are relatively very strong in the faint outlying parts of these nebulae. The planetary nebula B.D.¡2 degrees.1172 is seen in the ordinary telescope to consist of a circular disc (probably a sphere or spheroid) of light and a faint star in its center. When this nebula is observed with a slitless spectrograph the hydrogen and nebulium components are seen as circular discs, but the hydrogen discs are larger than the nebulium discs. In other words, the hydrogen forms an atmosphere about the central star which extends out into space in all directions a great deal farther than the nebulium discs extend. The Wolf−Rayet star−planetary nebula D. M. + 30 degrees.3639 looks hazy in a powerful telescope, and when examined in a spectroscope the haziness is seen to be due to a sharply defined globe of hydrogen 5 seconds of arc in diameter surrounding the star in its center. Wolf and Burns have shown that in the Ring Nebula in Lyra the 3726A and the hydrogen images are larger as to outer diameter than the nebulium images, but that the latter are the more condensed on the inner edge of the ring. Wright has in the present year examined these and other nebulae with special reference to the distribution of the principal ingredients. He finds in general that the radiations at 4363A and 4686A, of unknown or possibly helium origin, are most closely compressed around the central nuclei of nebulae; that the matter definitely known to be helium is more extended in size; that the nebulium structure is still larger; and that the hydrogen uniformly extends out farther than the nebulium; and that the ultra violet radiation at 3726A seems to proceed from the largest volume of all. The 37726A line, like the nebulium line, is unknown in stellar spectra; it seems also to be confined to true nebulosity. Neglecting the elements which have never been observed in true stars, we may say that all these observations are in harmony with the view that hydrogen should be and is the principal element in the outer stratum of the very young star. A few of the stars whose spectra contain bright hydrogen lines have also a number of bright lines whose chemical origin is not known. They appear to exist exactly at this state of stellar life: several of them have not been found in the spectra of the gaseous nebulae, and they are not represented in the later types of stellar spectra. The strata which produce these bright lines are thought to be a little deeper in the stars than the outer hydrogen stratum.

A slightly older stage of stellar existence is indicated by the type of spectrum in which some of the lines of hydrogen, always those at the violet end, are dark, and the remaining hydrogen lines, always those toward the red end, are bright. The brightest star in the Pleiades group, Alcyone, presents apparently the last of this series, for all of the hydrogen lines are dark except H alpha, in the red. In some of the bright−line stars which we have described, technically known as Oe5, Harvard College Observatory found that the dark helium and hydrogen lines exist, and apparently increase in intensity, on the average, as the bright lines become fainter. Wright has observed the absorption lines of helium and hydrogen in the spectra of the nuclei of some planetary nebulae, although the helium and hydrogen lines are bright in the nebulosity surrounding the nuclei. We may say that when all of the bright lines have disappeared from the spectra of stars, the helium lines, and likewise the hydrogen lines, have in general become fairly conspicuous. These stars are known as the helium stars, or stars of Class B. Proceeding through the subdivisions of Class B, the helium lines increase to a maximum of intensity and then decrease. The dark hydrogen lines are more and more in evidence, with intensities increasing slowly. In the middle and later subdivisions of the helium stars silicon, oxygen and nitrogen are usually represented by a few absorption lines.

Just as the gaseous nebulae radiate heat into space and condense, so must the stars, with this difference: the nebulae are highly rarified bodies, with surfaces enormously large in proportion to the heat contents; and the radiation from them must be relatively rapid. In fact, some of the nebulae seem to be so highly rarified that radiation may take place from their interiors almost as well as from their surfaces. The radiation from a star just formed must occur at a much slower rate. The continued condensation of the star, following the loss of heat, must lead to a change of physical condition, which will be apparent in the spectrum. It should pass from the so−called helium group, to the hydrogen, or Class A group, not suddenly but by insensible gradations of spectrum. In the Class A stars the hydrogen lines are the most prominent features. The helium lines have disappeared, except in a few stars where faint helium remnants are in evidence. The magnesium lines have become prominent and the calcium lines are growing rapidly in strength. The so−called metallic lines, usually beginning with iron and titanium lines, which have a few extremely faint representatives in the last of the helium stars, become visible here and there in the Class A spectra, but they are not conspicuous.

In the next main division, the Class F spectra, the metallic lines increase rapidly in prominence, and the hydrogen lines decrease slightly in strength. These stars are not so blue as the helium and hydrogen stars. They are intermediate between the blue stars and the yellow stars, which begin with the next class, G, of which our Sun is a representative.

The metallic lines are in Class G spectra in great number and intensity, and the hydrogen lines are greatly reduced in prominence. The calcium bands are very wide and intense.

Another step brings us to the very yellow and the slightly−reddish stars, known as Class K. These stars are weak in violet light, the hydrogen lines are substantially of the same intensity as the most prominent metallic lines, and the metallic lines are more and more in evidence.

Stars in the last subdivisions of the Class K and all of the Class M stars are decidedly red. In these the hydrogen lines are still further weakened and the metallic lines are even more prominent. Their spectra are further marked by absorption bands of titanium oxide, which reach their maximum strength in the later subdivisions of Class M.

The extremely red stars compose Class N on the Harvard scale. Their spectra are almost totally lacking in violet light, the metallic absorption is very strong, and there are conspicuous absorption bands of carbon.

Deep absorbing strata of titanium and carbon oxides seem to exist in the atmospheres of the Class M and N stars, respectively. The presence of these oxides indicates a relatively low temperature, and this is what we should expect from stars so far advanced in life.

The period of existence succeeding the very red stars has illustrations near at hand, we think, in Jupiter, Saturn, Uranus and Neptune, and in the Earth and the other small planets and the Moon: bodies which still contain much heat, but which are invisible save by means of reflected light.

The progression of stellar development, which we have described, has been based upon the radiation of heat. This is necessarily gradual, and the corresponding changes of spectrum should likewise be gradual and continuous. It is not intended to give the impression that only a few types of spectra are in evidence: the variety is very great. The labels, Class B, Class A, and so on to Class N, are intended to mark the miles in the evolutionary journey. The Harvard experts have put up other labels to mark the tenths of miles, so to speak, and some day we shall expect to see the hundredths labeled. Further, it is not here proposed that heat radiation is the only vital factor in the processes of evolution. The mass of a star may be an important item, and the electrical conditions may be concerned. A very small star and a very massive star may develop differently, and it is conceivable that there may be actual differences of composition. But heat−radiation is doubtless the most important factor.

The evolutionary processes must proceed with extreme deliberation. The radiation of the heat actually present at any moment in a large helium star would probably not require many tens of thousands of years, but this quantity of heat is negligible in comparison with the quantity generated within the star during and by the processes of condensation from the helium age down to the Class M state. We know that the compression of any body against resistance generates or releases heat. Now a gaseous star at any instant is in a state of equilibrium. Its internal heat and the centrifugal force due to its rotation about an axis are trying to expand it. Its own gravitational power is trying to draw all of its materials to the center. Until there is a loss of heat no contraction can occur; but just as soon as there is such a loss gravity proceeds to diminish the stellar volume. Contraction will proceed more slowly than we should at first thought expect, because in the process of contraction additional heat is generated and this becomes a factor in resisting further compression. Contraction is resisted vastly more by the heat generated in the process of contraction than it is by the store of heat already in evidence. The quantity of heat in our Sun, now existing as heat, would suffice to maintain its present rate of outflow only a few thousands of years. The heat generated in the process of the Sun's shrinkage under gravity, however, is so extensive as to maintain the supply during millions of years to come. Helmholtz has shown that the reduction of the Sun's radius at the rate of 45 meters per year would generate as much heat within the Sun as is now radiated. This rate of shrinkage is so slow that our most refined instruments could not detect a change in the solar diameter until after the lapse of 4,000 or 5,000 years. Again, there are reasons for suspecting that the processes of evolution in our Sun, and in other stars as well, may be enormously prolonged through the influence of energy within the atoms or molecules of matter composing them. The subatomic forces residing in the radioactive elements represent the most condensed form of energy of which we have any conception. It is believed that the subatomic energy in a mass of radium is at least a million−fold greater than the energy represented in the combustion or other chemical transformation of any ordinary substance having the same mass. These radioactive forces are released with extreme slowness, in the form of heat or the equivalent; and if these substances exist moderately in the Sun and stars, as they do in the Earth, they may well be important factors in prolonging the lives of these bodies.

Speaking somewhat loosely, I think we may say that the processes of evolution from an extended nebula to a condensed nebula and from the latter to a spherical star, are comparatively rapid, perhaps normally confined to a few tens of millions of years; but that the further we proceed in the development process, from the blue star to the yellow, and possibly but not certainly on to the red star, the slower is the progress made, for the radiating surface through which all the energy from the interior must pass becomes smaller and smaller in proportion to the mass, and the convection currents which carry heat from the interior to the surface must slow down in speed.