The actual period of exposures is very small, relatively, for a photographic zone; a ratio of perhaps one to thirty, for the meridian circle observations. But with the necessary observations of the comparison stars, for modern places, the completion of a zone of five degrees will be equivalent to five years work; while full meridian observation of such a zone would be equivalent to ten years work, a ratio of one to two.

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SPECTRAL TYPES IN OPEN CLUSTERS

By Robert J. Trumpler

Among the variety of objects that are included in the category of star clusters there is only one class that stands out distinctly from the rest: the extremely rich and highly condensed globular cluster. All the remaining objects are generally called *open* clusters; since they lie scattered along the path of the Milky Way, they might also be designated as *galactic* clusters. They are less distant than the globular clusters and contain in most cases stars bright enough for spectroscopic observations.

In a cluster we can consider all its members to be practically at the same distance from us. The absolute magnitudes of stars constituting a cluster then differ from their apparent magnitudes only by a constant, and this constant is a direct function of the distance. Star clusters thus offer an exceptionally favorable opportunity for studying the relation between spectral type and absolute magnitude. Trigonometric parallaxes as well as proper motions give us quite reliable data about the distances and luminosities of the dwarf stars of classes A to M; but so far this information is insufficient for B type stars which are of great luminosity and great average distance so that both parallaxes and proper motions are small and cannot be determined accurately. In many star clusters we find B type stars associated with dwarf stars of classes A, F or G. For these latter stars we can adopt the average luminosities of stars in general as obtained from parallax and proper motion measures, while spectroscopic and photometric observations of such a cluster tell us directly how many magnitudes a certain subdivision of class B is more luminous than those dwarf stars. The difference between the observed magnitudes of the cluster stars and the mean absolute magnitudes adopted for those spectral types further furnish the distance of the cluster.

In so far as clusters seem to be systems with common origin, and in so far as we can consider the spectral types to represent different stages of evolution, a study of spectral types in star clusters should give valuable help toward solving the problem of stellar evolution. The fact that in most clusters the stars cover a wide range of spectral types is capable of two interpretations. Either we may assume that the stars of a cluster do not originate all at the same time but vary in age, or we may follow the view that the origin of all cluster members falls in a limited period of time, that they vary, however, in original mass and on this account run through their evolutionary course with unequal speed and perhaps also following somewhat different courses of evolution.

With these problems in view an extensive program of spectroscopic observations of open clusters was undertaken. Two instruments are used for this purpose: the slitless quartz spectrograph attached to the Crossley reflector and the one-prism slit spectrograph of the 36-inch refractor. The first of these two instruments, designed by Mr. Wright, is described in *L. O. Bulletin*, **9**, 52. Operating somewhat like an objective prism it photographs the spectra of all stars within a field of 20′ diameter on the same plate. The dispersion of the two prisms is such as to separate the Hβ and Hϵ lines by 7.2 mm. Because of the dense crowding of stars in the richer clusters the spectra of several stars are often overlapping; in order to avoid this condition as much as possible, the spectra are widened very little. Although this makes the classification more difficult, the spectra can in general be estimated to a few tenths of a class. For each cluster one or two long exposures of 3^h

to 7^h are secured, giving useful spectra of stars up to the photographic magnitudes 13-14; if necessary shorter exposures are also made for the brighter stars. The field of the spectrograms includes the smaller clusters entirely, while it covers only the central parts of the larger ones. For a few of the largest clusters several plates with different centers are taken so as to obtain a more complete representation of these objects.

Twelve to fifteen of the brightest stars in each cluster are also being observed with the one-prism slit spectrograph for more accurate classification as well as for radial velocity. This part of the program is progressing more slowly because each star has to be observed separately. Both instruments combined so far furnish data for 52 clusters. While a complete evaluation and publication of these observations will yet take considerable time, a preliminary examination of the plates already gives some definite results which seem of sufficient interest to be communicated immediately.

For a statistical discussion of the estimated spectral classes it is best to relate them to the magnitudes of the stars; this is done by the construction of a *magnitude-spectral class diagram.* Each star of the cluster is plotted as a dot at the point which has the star's spectral class as abscissa and its apparent visual magnitude as ordinate. An example of such a diagram is found in Fig. 1 for the cluster *Messier* 34 (N. G. C. 1039). Graff's[1] measures were used for the visual magnitudes and the spectral classes were estimated on three slitless spectrograms of 20^m, 3^h, and $5\frac{1}{2}^h$ exposure. Six of the brightest stars had also been observed with the slit spectrograph.

The broken inclined line around which the stars are evidently scattering represents the dwarf branch. This line was constructed with Lundmark's[2] values of the mean absolute magnitudes of dwarf stars, adding to them a constant so determined as to fit the line closely to the plotted cluster stars. This constant is the apparent magnitude of a cluster star of absolute magnitude 0; its value was found to be $8^m.56$ corresponding to a parallax

[1] *A. N.*, **219**, 297, 1923.
[2] *Publ. A. S. P.*, **34**, 150, 1922.

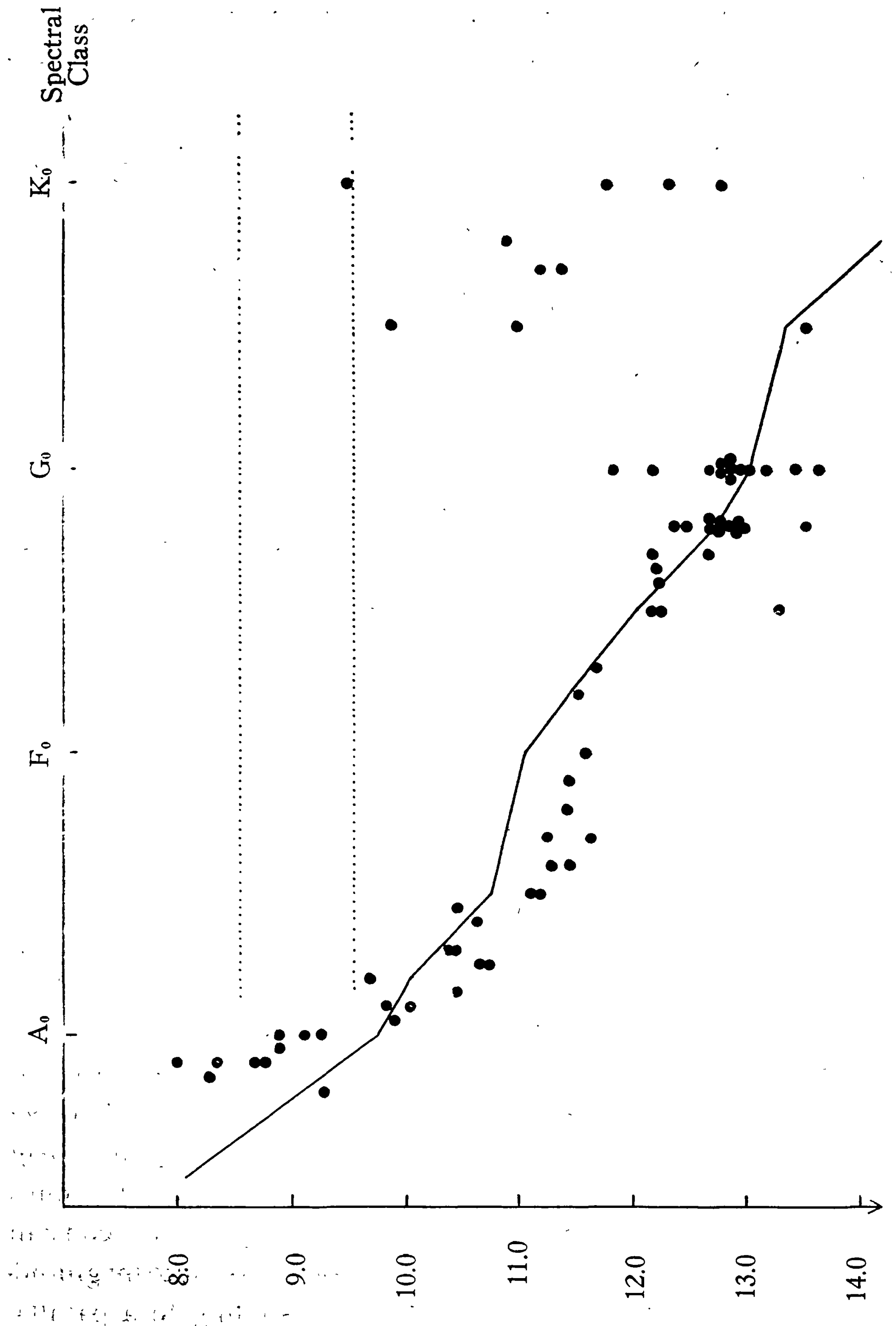

Fig. 1. Magnitude-Spectral Class Diagram for the Cluster Messier 34

of $''.0019$ or a distance of 515 parsecs (1700 light years) for Messier 34. The branch of giant stars lies between the two dotted horizontal lines at absolute magnitude 0 and $+1^m$. No clustering of dots is noticeable in this space; our cluster does not contain any yellow or red giant stars except perhaps one or two. A number of scattered stars fit neither into the giant nor the dwarf branch. This is not astonishing when we consider that all stars within 10′ from the center of the cluster were plotted and that among these there must be some stars not physically connected with the cluster but accidentally appearing projected on that part of the sky, while in reality situated before or behind the cluster. We should expect these background stars to be more numerous among the fainter stars and this is indeed the case in our diagram of Messier 34.

In the magnitude-spectral class diagram the background stars are somewhat disturbing, especially among the fainter stars and in those clusters that are not very rich in members. For this reason it is in general advantageous to use only the central part of the cluster where the percentage of physical members is largest. In many of the clusters observed for spectral class no accurate measures of the magnitudes are available and these had to be estimated from the exposure time and from the intensity of the spectra.

As a first result of our investigation the statement can be made that the members of each cluster exhibit a close relationship between spectral class and magnitude and that the magnitude-spectral class diagrams of clusters show a marked crowding of points along lines which can be identified with parts of the Hertzsprung-Russell diagram of giant and dwarf stars. Among the 52 objects so far investigated there is only one, N. G. C. 6885, for which this statement does not hold; this being a loose clustering of very little concentration is probably no physical system at all, but an accidental apparent agglomeration of stars.

Having identified the cluster members as giant or dwarfs, the A to G dwarf stars or the K type giants can be used for a determination of the distance of the cluster, as described above. The results thus obtained place the open clusters observed at distances ranging between 40 and 3000 parsecs, but most of them lie between 500 and 2000 parsecs. Some of the faintest clusters which are beyond the reach of the spectrograph may be situated at still larger distances, but the number of such objects so far discovered is relatively small.

In the magnitude-spectral class diagram of a cluster the few scattered stars not falling closely to the giant or dwarf branch may be taken for background stars. Justification for such a procedure is based on the evidence of the four nearest clusters (*Taurus cluster, Coma Berenices, Pleiades, Praesepe*) in which the individual cluster members can be separated from the background stars by means of their proper-motions. In these four systems no members are found outside of the two arms of the Hertzsprung-Russell diagram. In star clusters the dwarf branch appears as the most important part and it extends as one continuous line from types O or B_0 to the G or K dwarfs. The magnitude difference between class B and class A stars is found considerably larger in star clusters than generally adopted.[3] In eight clusters the average magnitude difference between class B_3 and A_0 is about $4^m.5$ and assuming for A_0 an absolute magnitude of $+1^m.0$ that of a B_3 star comes out as $-3^m.5$. This is more than two magnitudes brighter than the Mt. Wilson Table,[3] but is in better agreement with J. S. Plaskett's value of -4^m for the O type stars.[4] In order to fit the observations of open clusters, the dwarf branch must be drawn much steeper from A_0 to B_0 than from A_0 toward K_0 (see Fig. 2). The giant branch although rarely represented as a continuous arm like the dwarf branch may be traced by a horizontal line at about absolute magnitude $+0^m.5$. Only in a few of the nearest clusters, in which the physical members can be selected by their proper motion, is it possible to follow the dwarf branch to the K and M types. In most clusters the

[3]See the table p. 4 of *Mt. Wilson Contr.* 262, used for the determination of spectroscopic parallaxes.

[4]J. S. Plaskett, Problems of the 0-Type Stars: *Probleme der Astronomie, Festschrift fur H. v. Seeliger*, Berlin, 1924.

yellow or red dwarfs are too faint for spectroscopic observations and the instrumental limit is reached at the dwarfs of classes G, F, or even A.

Disregarding for the moment the end of the dwarf series, missing on account of instrumental limitations, we find that the open clusters represent the Hertzsprung-Russell diagram in different ways, emphasizing some parts more strongly, while neglecting others. It seems promising then to try a classification of open clusters according to the character of the magnitude-spectral class diagram. Although at the present stage of this investigation such an attempt is necessarily tentative, some of its features are definite enough to be given here.

The distribution of spectral types in open clusters varies essentially along two lines. On the one hand we find great differences in the proportion of cluster stars that fall on the giant branch (F-M). In class *1* we shall include clusters in which the giant branch is entirely missing or cases in which there are so few scattered stars falling within its limits that it must remain doubtful whether they are physical members or background stars. Class *2* comprises the clusters which show a marked crowding of stars along the giant branch although their number may still be small compared with that of the dwarf stars. There is not quite sufficient evidence yet for the establishment of a third class in which the yellow and red giant stars are very numerous and form the most important constituents of the cluster.

The dwarf series, as defined above, on the other hand, while always present does not always extend equally far in the direction of the hotter spectral types. We shall designate with *b* those clusters in which the dwarf branch reaches up to the spectral classes B_0-B_5. Clusters of class *a* contain no types of higher temperature than B_8, while those of class *f* are entirely composed of stars with spectral types F_0-M. A priori we might expect the existence of all possible combinations of *1* and *2* with *b, a, f;* so far, however, only the following four were found to be represented:

1b: The brightest cluster stars are of type B_0-B_5, including occasionally an O type star. The fainter stars are closely crowding around the dwarf branch, tracing it continuously down to the instrumental limit. Giant stars A_5-M are entirely missing or very rare. Typical examples are h and χ *Persei,* Messier 36, Messier 35, the *Pleiades.*

1a: The brightest cluster stars are of class B_8-A_5; the fainter stars follow the dwarf branch closely. No stars of class B_0-B_5 are present and no or very few giant stars. Typical examples are Messier 34 (See Fig. 1), N. G. C. 1647, Messier 39.

2a: The brighter cluster stars are scattered along the giant branch from B_8 to K, the fainter stars follow the dwarf branch from B_8 toward F and G. In general the giant branch is not uniformly represented but shows a concentration at G_5-K_0; around class A, where the giant and dwarf branches meet the stars are numerous and pretty much scattered. Often there is even a marked gap in the giant branch between A and G making the G_5-K_0 giants appear as an isolated group. The dwarf branch is continuous. Typical examples are: Melotte 210, Messier 37, Messier 11, *Praesepe, Taurus cluster, Coma Berenices*:

2f: No stars of classes B or A are present. The brighter stars follow the giant branch from K to F, which turns somewhat down to reach the F dwarf stage; the points are rather widely scattered at this point, and the fainter stars seem to follow the dwarf branch from F_0 to G. N. G. C. 752 is the only representative of this class so far met with, but N. G. C. 6811 is intermediate between *2a* and *2f* containing no stars of hotter types than A_5.

The magnitude-spectral class diagrams characteristic for these four types are illustrated in Fig. 2. The full lines drawn are the axes of the giant and dwarf branches (Hertzsprung-Russell diagram) while the shaded areas mark the regions covered by the plotted cluster stars. The four types are somewhat arbitrarily selected, in reality there is a gradual transition between them. A diagram showing the relationship of these types is found in Fig. 3. The arrows indicate the principal lines of transition of which evidence is given by intermediate representatives.

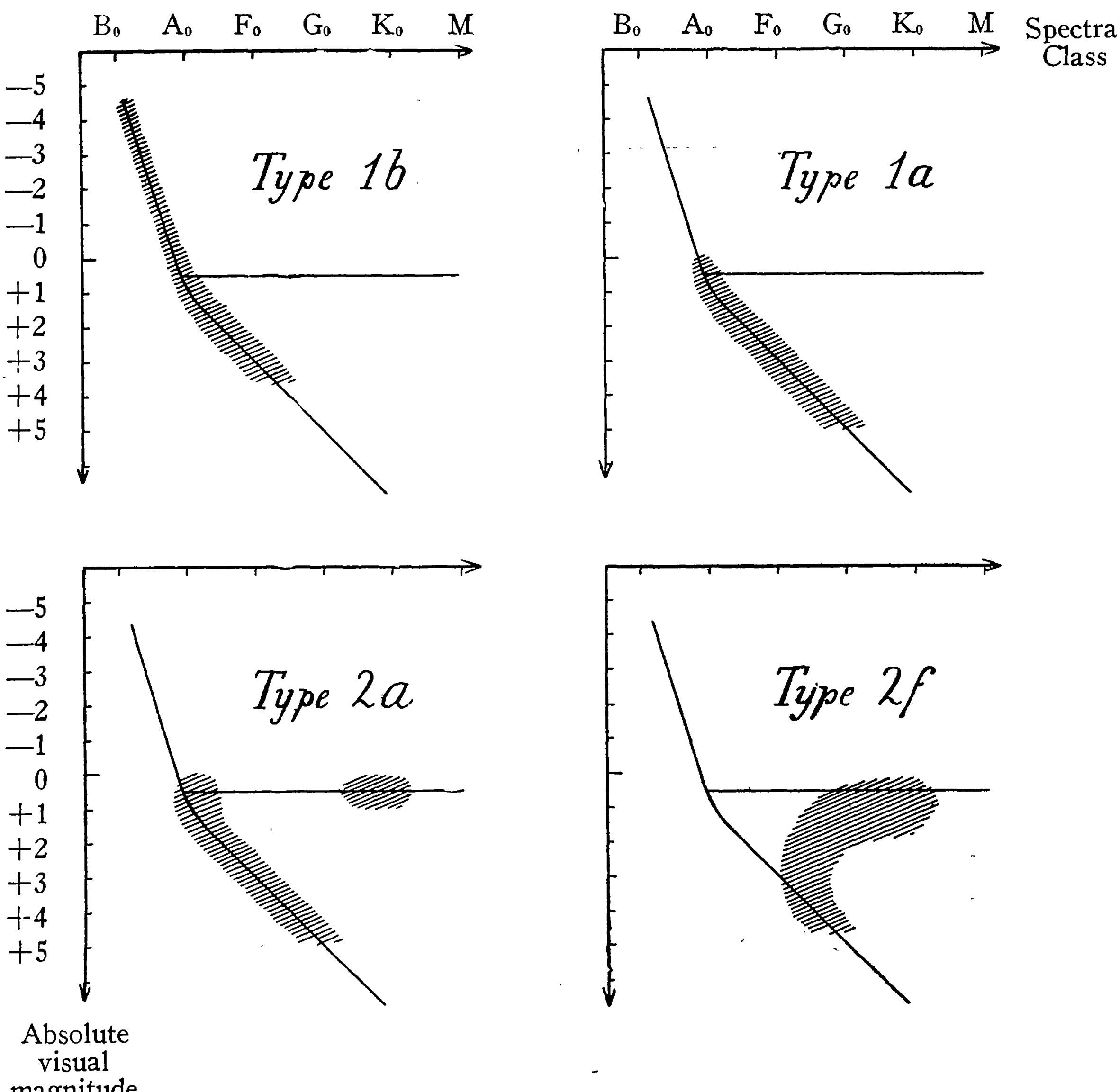

Fig. 2 . Magnitude-Spectral Class Diagrams of four Cluster Types

Some of the clusters of type *1b* possibly include a few isolated yellow or red giant stars; this is illustrated in Fig. 3 by the short arrow leading from *1b* in the direction of *2b*. There is, however, no case of type *b* in which such giant stars are sufficiently well represented to justify the establishment of a class *2b*. Perhaps the most striking result of the investigation may then be expressed by the statement that open clusters containing stars of spectral class B_0-B_5 contain no or very few yellow giant stars.

There is indication of a transition from type *2a* toward an

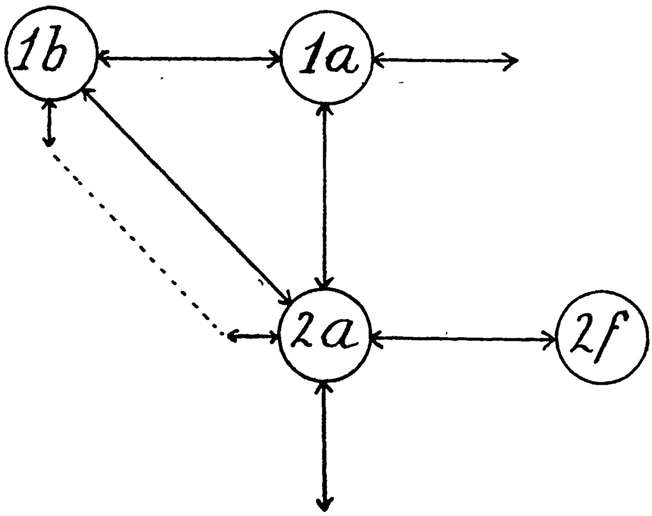

Fig. 3. Relationship of the Four Cluster Types

eventual type *3a*, the existence of which is yet doubtful. In both of its possible representatives (Messier 67 and N. G. C. 6939) the observations do not extend far enough toward small luminosities. N. G. C. 6866 forms a transition from *1a* in the direction of *1f*, as it does not contain members of hotter type than A_3.

The 52 clusters examined are distributed among the four types in the following manner:

Type *1b*	:	24
1a	:	6
2a	:	20
2f	:	1
No physical system		1

Types *1b* and *2a* are the most frequent and the former seems characteristic for the many small cluster knots scattered throughout the Milky Way.

What is the relation of this classification to the probable evolution of open clusters? As the cluster types differentiate along two arguments it is evident that they do not form one single series tracing the path of evolution. There seems to be another factor besides age playing a roll in determining the type of a cluster. This second argument may be furnished by the *original mass* of the cluster members. In other words, a cluster containing very massive stars follows a different course of evolution than a cluster consisting of small masses. The line of classification from *3* to *2* to *1* in the direction of diminishing proportion of giant stars undoubtedly relates to increasing age. The question whether a cluster stops at the *f* stage or passes through this to the *a* or even the *b* stage depends on the masses of the constituent stars.

This hypothesis is now able to give an explanation why, in open clusters, stars of types B_0-B_5 do not occur together with yellow or red giant stars. The *b* stage evidently is reached only by clusters including stars of very large mass, and in these clusters the masses of the stars cover a wide range. Assuming all stars of such a cluster to originate at the same time, the largest masses go through their evolution more slowly and by the time they reach the classes B_0-B_5 all other stars have passed into the dwarf stage, and there are no yellow or red giants left. The evolution of such a cluster would then lead from *3* through *2a* directly to *1b* and then toward *1a, 1f,* etc. A cluster of intermediate mass would pass from *3* through *2a* to *1a* and then toward *1f,* etc., while a cluster built only of stars of small mass would pass through *2f* toward *1a* or *1f,* but such cases evidently are rare. We might have been tempted to arrange the four types in the order *2f-2a-1b-1a-1f,* etc., as a continuous series of evolutionary stages, but the transition from *2a* to *1a* is speaking against such an interpretation, and this transition is indeed very gradual and well represented.

As a whole, the spectroscopic observations are in good agreement with the hypothesis that all stars of a cluster originate at the same time or within a limited period, that the stars differ in original mass and run through their evolutionary course with different speed. If these views are correct we are led to the conclusion that the open clusters are already of considerable age; otherwise we would not find the dwarf branch so well formed in all cases, nor could we explain the general scarcity or total absence of yellow and red giant stars. As class *1b* and the immediately adjoining stages are by far the most frequent, we might even say that the open clusters seem to be of similar age.

How the statistical constitution of a cluster is related to its type is to be investigated numerically by star counts. One feature, however, is apparent. In clusters of type *1b* the twenty brightest stars, for instance, are distributed over a fairly large range of brightness, while in types *2a* or *2f* they are more nearly of the same brightness. In the first case the luminosity law rises very gradually, in the second case more abruptly. But the appearance and constitution of a cluster is still more affected by its *"membership"*: the total number of stars it contains. Some of the open clusters appear as groups of only a dozen or a few dozen stars, others are large systems of several hundred or even a few thousand stars. That the *"membership"* is independent of the type is well illustrated by a comparison of two clusters which are of the same type and situated at nearly the same distance. Such a pair e. g. is h *Persei* and N. G. C. 1502 of which the former is comparably richer in stars and larger in dimensions; another example is furnished by Melotte 210 and N. G. C. 6633.

"Membership" and cluster type are probably the most important factors defining the constitution of a cluster; the first describes the order or size of the system, the second its stage of evolution and the order of stellar masses contained in it.