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MAGNITUDES AGAIN[1]

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(1) A YARDSTICK WITHOUT SUBSTANCE

AN assemblage of astronomers scarcely needs reminding that stellar magnitude is the measuring stick with which we sound the depths of space. Upon this unit, in some way or other, depend our distances of all the more remote objects in the heavens and, indeed, the dimensions of the universe itself, as far as we know it. Triangulation, the perspective-sharpening of star streams and the backward sweep of stars which reflects our own forward motion through space locate our nearer neighbors; but we quickly pass the useful limit of such methods and thereafter must deal with distances so great that no change in the position of the observer produces any answering shift in the faraway star. The principle of measurement is exhausted, and a new one must be found.

[1] Address of the retiring vice-president and chairman of the section on astronomy, American Association for the Advancement of Science, Indianapolis, December 28, 1937.

You all know how this need has been met: The intrinsic brightness of an object being known—how we find that item is of no concern here—we observe its apparent brightness, which is only intrinsic brightness dimmed by distance, and apply the faithful inverse-square law. Magnitude is, of course, only a convenient numerical expression of the brightness. A sound and satisfying principle, you say, which meets our need admirably. It oversteps ordinary limits of distance and demands only that the object send us enough light to tell us what it is, and thus enable us to say how bright it is intrinsically.

As astronomers you know that in practice matters are not quite so simple as this expression of the essence of the problem would imply; but I have ignored difficulties in order to emphasize once more that stellar magnitude, our customary measure of brightness, takes rank as an observational datum of major importance.

(2) BRIGHTNESS AND SOME CIRCUMSTANCES

At this point some one remarks, But what is brightness? The questioner, if not a physicist, at least will be a physical-minded individual primed with an array of facts about radiation. Well, the brightness in question depends upon circumstances; and, with that, a fringe of uncertainty envelops the problem to the distraction of the observer and the confusion of those who would interpret his results.

One of these circumstances may be the human eye, with its peculiar distribution of retinal sensitivity to both color and intensity and subject to such disturbance of sensation as the Purkinje phenomenon. And, besides, eyes, like height and other physical characteristics of the individuals to whom they belong, differ. Statistically, we may talk about an average eye, but the brightness of a star is not measured by a statistical fiction. The individual human eye that actually does the job is likely to differ so erratically from the fiction that as an instrument for measurement it inspires us with no high confidence.

Another circumstance very probably will be a photographic plate, one of the numerous brands to be had in the market. In these days all workers in physical science know something about plates and the surprises they may spring on the unwary. No two, even from the same box, are exactly alike. Genetically they may be identical twins; but, unless treated with the most meticulous impartiality, they are likely to suggest divergent strains of heredity. Then, too, photographic plates may display a Purkinje phenomenon of their own. It by no means follows that a plate showing the same responsiveness to red and blue light of specified intensities will maintain that equality of response when the intensities are increased or diminished ten or a hundred fold.

Still another possible circumstance is the photoelectric cell, which, with all its precision, has its own peculiarities; and in its behavior always differs from both the eye and the photographic plate.

A totally different kind of circumstance is the atmosphere that envelops the earth; and still others are the glass of the objective and the silver or aluminium surface of the mirror in the telescope with which stars are observed.

The eye, the photographic plate and the photocell operate as receivers and, with various auxiliaries, as recorders of radiant energy; the atmosphere and the image-forming parts of the telescope, however useful they may be in other particulars, behave as unwanted filters which strain out a regrettable fraction of the radiation falling upon them. The dull red globe of the setting sun contrasted with its midday brilliance shows in exaggeration what our atmosphere may do to the color and the intensity of radiation. The changes depend on the momentary state of the atmosphere and the distance of the star above the horizon. They fluctuate from night to night, and sometimes from hour to hour, with the capriciousness displayed by all meteorological phenomena.

The silver coat of the ordinary reflecting telescope deteriorates rapidly and thus also modifies, unpredictably, the color value of the radiation passed on to the photographic plate, or whatever may be used as a receiver. The objective of a refracting telescope at least has the merit of permanence; but the filtering effect of objectives varies between wide limits, and no objective behaves exactly like a reflecting surface of silver or of aluminium.

As a final complication in the measurement of brightness, in photographic photometry at least, the recorded brightness varies with the position of the stellar image relative to the optical axis (distance from the center of the plate) and often on the size of the image as well. Although a time-consuming nuisance, this difficulty can be overcome with patience and may be forgotten for the moment to brighten a little a rather gloomy outlook.

(3) MAGNITUDE, FROM PHYSIOLOGY TO PHYSICS

Having passed in review an array of circumstances which modify measurements of brightness, it is time that I say something about brightness itself. Any such statement, if illuminating, will include a few sentences of astronomical history, interesting as well as important because they concern the rather unusual transfer of a physiological concept into the realm of purely physical concepts and units.

Originally, brightness referred to the intensity of the visual sensation produced by a luminous object; and even now to most people it probably has only that old connotation. And the magnitudes—perhaps Ptolemy's, perhaps from Hipparchus three hundred years earlier, but at any rate preserved and transmitted to us by Ptolemy's catalogue of 1,800 years ago—those ancient magnitudes, which are the ancestors of record of all our magnitudes to-day, are simply rough estimates of visual sensation. More or less accidentally these estimates acquired a numerical expression, accidentally because the six classes of brightness into which the naked-eye stars originally were sorted happen to have been designated by numbers.

In the centuries following Ptolemy an occasional figure of distinction, Al Sufi, Ulugh Beg, Tycho, for example, gave the matter enough attention to repeat, or in some cases revise, the ancient estimates. Later, Ptolemy's system was extended to telescopic stars. Flamsteed, Lalande, John Herschel, Bessel and especially Argelander and Schönfeld observed literally hundreds of thousands of stars; but all these observations were still simply estimates of visual sensation, and, aside from some numerical refinement, nothing very essential happened until the discovery of Fechner's psycho-physical law in 1859. Expressing as it does a relationship between sensation and the stimulus producing the sensation, this law gave for the first time a rational statement of the connection between the subjective experience of brightness and the objective physical cause. That Fechner's law has only limited applicability is not now of much consequence for photometry. The significant point is that its form determined the course of subsequent events.

You recall how the law runs—that the *absolute* change in sensation is proportional to the *percentage* change in the stimulus. Applied to stars and set down as a formula, it leads to the familiar relation that the difference in the magnitudes of two stars is proportional to the logarithm of the ratio of the intensities of the light we receive from them. This relation was first discovered empirically by Steinheil in 1836 and later verified by others; but it was Fechner's fundamental investigation that gave it the vitality which insured fruitful applications.

There was, of course, the question of units and zero point, which need detain us only to remark that whoever first sorted the lucid stars into six classes unwittingly assigned to unit magnitude the value it has to-day. Again you will recall what happened. Actual measurements of starlight with photometers, which had meanwhile been devised, showed that an intensity ratio of 1 to 100 in the light of two stars corresponded so closely to a difference in brightness of five magnitudes on the traditional scale that this convenient numerical relationship was adopted as a definition of unit magnitude.

You will observe that magnitude now appears in physical dress. Starting as an expression and measure of sensation, magnitude maintained its physiological aspect for centuries; then suddenly the physiological unit disappears to be replaced by a new unit, bearing the same name and of sensibly the same numerical value as the old one, but defined in terms of physical concepts. In fact, magnitude difference thus becomes only a mode of expression for relative intensity—that is, of the relative energy flux per unit area received by the observer. Following tradition, we still speak of magnitude as a measure of brightness; but the brightness meant is concerned not with the subjective features of sensation but primarily with properties of stellar radiation.

It is also noteworthy that these ideas adapted themselves easily to the conditions of photography when this substitute for the eye found use in the measurement of starlight. The source of this welcome simplicity is a certain rough analogy between the eye and the photographic plate. A significant characteristic of the photographic image of a star, and the thing the most easily measured, is its size. But both size of image and photographic density, an alternative and sometimes more advantageous expression of the photographic effect, resemble the subjective sensation of brightness: To a first approximation, both bear a logarithmic relation to the intensity of the external exciting cause. Consequently, the characteristics usually measured on the plate stand in a simple, nearly linear relation to the physical stellar magnitude. Photographic magnitudes thus naturally ranged themselves alongside those derived, first, by visual estimates and, later, from visual measurements of intensity made with photometers.

But since physical concepts have so come to the fore, you ask, Why not express measurements of intensity directly in energy units, thus obtaining results of immediate physical significance? It is not tradition alone that has so firmly established the physical concept of magnitude. We still make visual estimates of brightness, or better, of differences in brightness; the step method of Argelander, for example, is still of great value. And for easy comparison of results we prefer the traditional unit. Then, too, there is a further item of convenience. We deal to-day with intensities differing as much as a hundred million to one. The awkwardness of such numbers is obvious; but put them in logarithmic form, as we do when we turn them into magnitudes, and three or four significant figures suffice to express the entire range of relative intensities with all needed precision.

So much for that rather ambiguous term, brightness, and its dual connection with visual sensation and with physics. Its clarification has given us magnitude, which, although suggestive of its own historic origin, is only a convenient mode of expressing energy received per square centimeter per second of time. Now we may turn back to those attendant circumstances which in specific cases determine what magnitude is to be.

(4) CIRCUMSTANCES AGAIN, AND A FORMULA

Stars behave enough like black bodies to suggest that the range in wave-length of the radiation they emit is large. We can measure, however, only the radiation transmitted by the earth's atmosphere, extending from the abrupt cut-off at wave-length $0.29\ \mu$ due to the broad ozone band to an upper limit which, with some gaps, now stands close to $23\ \mu$—an interval of about six octaves. The range for the eye is a little short of an octave. The photographic plate and the photocell may or may not—usually not—do a little better. Further, the restricted ranges of sensitivity for these receivers of various kinds do not coincide.

Ordinary magnitudes therefore bear no simple relation to the total energy radiated by stars and, moreover, are of diverse kinds—visual, photographic, photovisual, photoelectric, for example.

The facts for a given case may be stated symbolically by the formula:

$$M = -2.5 \ \log \int_0^\infty \frac{\pi r^2}{\zeta^2} E(\lambda, T) A(\lambda, z) T(\lambda, d, m) R(\lambda, m) d\lambda + \text{const.} - 2.5 \log \frac{\zeta_0^2}{\zeta_0^2}.$$

Mathematically, this forbidding expression for the apparent magnitude of a star is definite enough; but in practice its symbols remain for the most part undetermined. Nevertheless, the equation is useful because it illuminates the concept of magnitude and, at the same time, sets up finger posts pointing toward possible dangers. It expresses a proportionality between magnitude and the logarithm of the energy flux received per unit area at the point of observation (ergs sec^{-1} cm^{-2}), multiplied by certain reduction factors and summed over the entire range in wave-length λ. The factor 2.5 is Pogson's coefficient, which fits the unit for m as closely as possible to the system of the early visual estimates. The minus sign records a minor accident of history—that whoever first assigned numbers to the six original classes of brightness pinned the numeral "one" to the brightest stars, instead of the other way around. The constant of course fixes the zero point for the magnitude scale. The purpose of the superfluous zero term involving ζ_0 will appear in a moment.

Thus far we have only a formal statement of tradition adjusted to the needs of precision. As for the details of the equation, a little dissection proves it less incomprehensible than it looks. Clearly there are four functions, each dependent on the wave-length, and, potentially at least, on other things too. The distance of the star, ζ, and its radius, r, are thrown in for good measure, to remind us that apparent magnitude does depend on the distance and the size of the star and to enable us to begin with E, the energy function of the star, whose emission is determined by its temperature T.

E, here expressed as surface intensity (energy flux for the wave-length interval λ to $\lambda + d\lambda$ per unit solid angle summed over unit area of the radiating surface), is, of course, peculiar to the star—in general, however, a more-or-less close approximation to the black-body law of the perfect radiator. Together, E, r and ζ give us the energy flux received per unit area just outside our atmosphere—you will recall that hitherto we have always talked about energy received. A and T express the fractions of incident energy which escape the filtering action of the atmosphere and the telescope. Besides λ, the zenith distance of the star, z, and its distance from the optical axis of the telescope, d, are involved here, and possibly also m itself, which may influence the distance correction. Finally, R stands for receiver and measures the fractional response of the eye, plate or photocell; in short, it is the sensitivity-curve which determines what kind of magnitude m is to be—visual, photographic, photovisual, etc. The appearance of m in this function is a warning to be on guard against the Purkinje phenomenon.

The zero-point constant involves more than one might think and deserves comment. In practice it is always the magnitude of another star, some standard reference object, and hence 2.5 times the logarithm of an integrated intensity precisely similar to the first term on the right of the formula. The entire expression is therefore the equivalent of the logarithm of a quotient. This circumstance has the important consequence that the numerical value of m is independent of the particular physical units used for its definition; we might, for example, have used energy density instead of energy flux. And hence it is that astronomers sometimes talk of magnitude with such unconcern for the physical significance of the thing with which they are dealing. It is only when the standard reference object is compared with a terrestrial source for reduction to absolute units that there must be careful watching of steps if confusion and error are to be avoided.

Another matter of real importance lies hidden in the constant: If the reference object and the star in question are of the same spectral composition, and if both are observed under the same conditions, with precautions to avoid the Purkinje phenomenon, all the functional relations, as well as the physical units, drop out from the quotient and we are left with the ratio of the *total* energies radiated by the two stars. In particular, the receiver with its restricted range of sensitivity cuts no figure, and in the case of visual magnitudes the last trace of a connection with physiological sensation disappears.

Finally, as for the apparently meaningless term in ζ_0, this intrusion shows how easily magnitude becomes a magic wand for summoning forth distances of stars. Interchange ζ_0 in the denominator of this term with ζ in the first term. The value of m remains the same. The first term on the right, however, together with the constant, becomes m_0, the apparent magnitude of the star seen from the distance ζ_0. Think of ζ_0 as a conveniently chosen standard distance, ten parsecs in practice, to which the light of all stars may be referred as a means of revealing their differences in intrinsic brightness. The quantity m_0 is, accordingly, the so-called absolute magnitude of the star, usually denoted by M. The zero term is no longer zero, but a simple function of the star's distance expressed in ζ_0 as a unit.

We thus obtain a relation which shows, as already said, that m is only the intrinsic brightness of a star dimmed by distance,[2] and from which distance may be found when absolute and apparent magnitudes are known. The status of magnitude as a yardstick of distance justifies this digressive paragraph on so familiar a relation.

It is doubtless a happy circumstance that Hipparchus and Ptolemy did not know about this formula, even without its superfluous term. Naïve approach to a problem often has insured its solution.

With such a statement, this part of my discussion seems to be nicely rounded off to a finish; and not so many years ago it might have been left at that. But to-day we know too well that light gets lost on its way through space for us to be deceived by a rhetorical ending. Nevertheless, I do not intend to say here what interstellar absorption does to our formula, but only let you know that it has not been wholly forgotten. It modifies our conclusions, of course, but does not greatly affect the observational procedure. Usually we measure magnitudes as though absorption were not present, and then from our results try to find if it is present, and to what extent.

(5) The Fountain of Troubles

Viewed in the light of the unpredictabilities described for eyes, photographic plates and the atmosphere surrounding us, our symbolic expression shows why photometry to some extent stands in bad repute. And that is part of the value of the formula, which although not usually a basis for either observation or calculation is an excellent summary of the ways in which uncertainties get into our results.

To illustrate, note again that each of the functions E, A, T, R depends on the wave-length λ. Each element of the surface intensity E under the summation sign is modified in succession by A, T and R. If now A, T and R change, that is, if the conditions of observation change, the modifications themselves are modified, and in a different way for each small interval of wave-length. The effect on m depends on the sum of these incremental changes. Moreover, since E depends on the temperature of the star, the disturbance in m produced by changes in the atmosphere, the telescope and the receiver also depends on stellar temperature; blue stars behave differently from red stars.

The ideal of observations made always under the same conditions can not be attained. The visual observer must use his own eye and the telescope at hand. We might agree all to use the same kind of photographic plate, treated in the same way or the same type of photocell; but it is not worth while, because the telescope with which the observations are made can not be standardized.

Important departures from uniformity in the observational data are therefore inevitable. Each observer can standardize the conditions affecting his own measures—the use of his eyes, the handling of his plates, the arrangement of his observations; and he can attend to the erratic behavior of the atmosphere by observing different stars at nearly the same altitude and always as close to the zenith as possible. To utilize the high precision of the photocell, he can be even more cautious, testing the atmospheric transmission from night to night and treating different stars appropriately to their colors. All this may be done; but in the end we face the unyielding fact that observational results obtained with different eyes and different instruments are inherently inhomogeneous, and, to be of ultimate worth, must be standardized by reduction to a normal reference system.

(6) Another, Only Mentioned

Before passing to the logical sequent of the preceding paragraph I must again call your attention to the coefficient 2.5, unobtrusive, even though at the forefront of the symbolic expression for magnitude. The true inwardness of this number is revealed by noting that its reciprocal, 0.4, is the logarithm of the ratio of two intensities whose difference in brightness is exactly one magnitude—the essence, therefore, of the definition of unit magnitude and, as such, the center of the struggle for law in the millions of m's to be found in our catalogues. In short, this coefficient of Pogson's fixes the scale of magnitudes.

To find the magnitude of a star in accordance with this scale naturally requires some kind of measurement of the intensity of starlight. Beyond a statement of principle and a rather obvious inference, I do not intend to say anything about such measurements here. The subject is long and involved; moreover, some of the more serious difficulties originate in matters already mentioned and still to be discussed.

As for method, usually we reduce the light of a star by a known amount—with the aid of a diaphragm, a grating, a screen, a pair of polarizing prisms or some equivalent device—then find a second, fainter star whose intensity, unchanged, produces the same effect on the eye or the photographic plate as the reduced intensity of the first star. The logarithm of the reduction factor, multiplied by that critical coefficient 2.5, is the magnitude difference of the two stars. We thus proceed by an equalization of intensities, equality in intensity being judged by likeness in visual or photographic effects.

The practical outworking of this principle affords endless opportunity for ingenuity in avoiding or elimi-

[2] Except in the rare case that the star's distance is less than ten parsecs; then the apparent magnitude is brighter than the absolute value.

nating a great variety of disturbances that may influence the accuracy of the magnitude scale. But whatever the effort, the precision in the scale always falls far short of that easily attained in measurements of things that can be touched or weighed.

Under favorable laboratory conditions judgments of equality in visual and photographic effects are uncertain by about one per cent.; but actual observing conditions are always far below those of the laboratory. The interval measurable in a single step seldom exceeds two or three magnitudes, corresponding to an intensity ratio of, say, 15 to 1. Since modern telescopes encompass an interval of twenty magnitudes, or a ratio of a hundred million to one, many successive steps are required to cover the entire range. Any systematic error of measurement is cumulative and easily becomes serious, while the accidental errors alone swell to an unpleasant total.

(7) AN ACHIEVEMENT—WE HOPE

The practical derivation of magnitudes follows two main lines, seeking, first, standards of magnitude—precise values for a relatively small number of stars covering a wide range in brightness; and second, utilization of such standards in measurements of other stars, sometimes an individual, sometimes a group, and sometimes the thousands of stars required for statistical discussions relating to the size and the structure of our stellar system.

Although there are details enough to keep the observer nimble-witted, the transfer of the scale of a group of standards to stars in other parts of the sky follows a comparatively simple procedure; and properly used, the process gives reliable results.

Standards themselves require more attention. To set them up the scale of magnitudes defined by Pogson's coefficient must be established by methods outlined briefly a moment ago. This part of the problem we now hope is mostly a matter of history. For fifteen years the North Polar Sequence has served reasonably well and probably represents the most anxious part of the effort required to establish a satisfactory system of reference magnitudes.

Selected by Pickering, only a few stars at first, this famous list of standards had by 1912 grown to the 96 objects now familiar. Extensive measurements at a half dozen observatories gave finally the list of mean magnitudes presented to the International Astronomical Union in 1922. The photographic scale is covered from magnitude 2.5 to 20.1; the photovisual, from 2.1 to 17.4. Below 19.0 and 15.5, respectively, the means include only a few Mount Wilson observations and scarcely deserve the sanctity of standardization.

Please note that these standards do three things: serve as exemplars of the photographic and the photovisual scales; fix the zero points of both scales; define a reference system of colors for stars. This is a good order in which to state the facts; but to talk about them we begin with the notion of standard colors.

Reflection on the formula for magnitude has shown us that results as they come from the telescope lack homogeneity, and a little further reflection indicates that to attain homogeneity we require standards of color.

To be more explicit, we note that magnitude derived with an ordinary photographic plate sensitive to the violet and blue usually differs from the visual or photovisual magnitude, corresponding to a maximum sensitivity in the yellow. Together, these two classes of magnitudes constitute a restricted spectral photometry which determines the integrated brightness of two rather wide regions in the spectrum. Even so, the photographic and photovisual magnitudes are sufficient to indicate the temperature of a star; or, as we more commonly put it, the difference of these magnitudes (color index) is a measure of the color of the star. Moreover, since the radiation function of a star (E, in our equation) is approximately that of a black body, the color index turns out to be nearly proportional to the reciprocal of the star's temperature.

Now the differences between separate series of photographic (or photovisual) magnitudes originating in the telescopes, plates, etc., which we designate as inhomogeneities, resemble the differences between photographic and photovisual magnitudes; they are only smaller. These small disagreements between magnitudes of the same kind which cause so much trouble are therefore also proportional to the reciprocal temperature, or, better still, to the color index.

Because of this simple relation knowledge of color indices opens the way to a unification of series of magnitudes which in themselves are not directly comparable. The procedure of course presupposes a reference system of color. The system adopted for the international standards is that defined by magnitudes obtained with the silvered reflector and plates of the ordinary silver-bromide emulsion.

The zero points fixed by the international standards represent an attempt to satisfy a convention adopted by the Committee of the Astrographic Chart in 1910, namely, that the mean photographic magnitude of A0 stars between magnitudes 5.5 and 6.5 should equal the mean Harvard visual magnitude of these stars. The color index of an A0 star would thus be zero. For the region of the North Pole these conditions are approximately satisfied, the color index for A0 being not quite zero, but -0.04 mag. instead.

Recently, however, we have found that a thin veil of interstellar dust cloud obscures the stars in the polar region and makes them about 0.1 mag. redder than normal. Stated in another way, color indices of A0 stars in regions unaffected by selective space absorption which have been derived by comparisons with the polar standards average about -0.14 mag. The convention of 1910 is therefore not generally satisfied and as it stands is incomplete. The sensible thing seems to be to abandon the original definition and accept the Polar Sequence magnitudes themselves as a definition of the zero points, which would thus merely continue a practice already established by fifteen years' usage.

As for the scales themselves, it is hard to say with assurance how closely they fit the definition of unit magnitude. I have already expressed reservation about some of the faintest stars of the sequence. For other parts of the scale the internal agreement of abundant data obtained by different methods and at different observatories has always inspired a good deal of confidence in the results.

The most searching test, however, is one recently made with the photoelectric cell by Stebbins and Whitford. The high precision of this instrument and its complete independence of all the traditional methods of photographic photometry give the test unusual importance. When reduced to the standard photographic scale, the measured interval of about nine magnitudes from Polaris down to magnitude 11.5 agrees within a few hundredths with that shown by the standards. Between 6.5 and 11.5 the systematic differences for groups of four stars each reach 0.02 mag. only once, and the average difference for individual stars is ± 0.017 mag.

The only doubtful point concerns stars 1 to 4 of the sequence, for which there is a mean difference of 0.10 mag. The magnitudes for these stars, which are all of early A type, would seem, however, to require a supplementary correction for color, of the right sign and possibly of the right amount to remove the discrepancy. This correction originates in Balmer-line and continuous hydrogen absorption, which affects the standard magnitudes but not those obtained with the photocell. Since departures from black-body radiation are involved, the required color correction stands in no simple relation to color index and can not be determined from the data now available.

This difficulty illustrates a defect in the Polar Sequence standards: there are not enough of them and they include no B-type stars. Had a representative selection of types been available, the supplementary correction for hydrogen absorption could have been determined directly from the data used for the comparison.

Again, a final reference to our formula reminds us that the transmission function for the telescope may depend on magnitude and on distance from the optical axis and that reductions to the standard color system also frequently depend on magnitude. The observer is certain to meet these conditions in using large-field, short-focus cameras. The number and distribution of the present standards is wholly inadequate to a satisfactory determination of the complicated instrumental corrections required to neutralize these disturbances. To remove this deficiency we have measured at Mount Wilson, in an investigation now nearing completion, photographic and photovisual magnitudes of a large number of stars north of $+80°$ declination and down to about the eleventh photographic magnitude to serve as supplementary standards.

(8) EXHORTATION TO THE OBSERVER

Twice already have I referred to the inherent lack of homogeneity in photometric data. Now admonitions are to follow; most important of all, that the observer either reduce his results to the international system or at least provide the means of doing so.

The discharge of this obligation is less onerous than would be expected from the formal expression for magnitude. Since the corrections required are nearly proportional to the color indices of the individual stars, the calculation is simple. But I must immediately warn you that the expected proportionality of color correction to color index is not always realized. Departures from black-body radiation may interfere, as for example in the early A stars just cited, whose magnitudes presumably are affected by hydrogen absorption. A more detailed investigation is then required.

At this point note a significant detail: If magnitudes are to be reduced to a fundamental system, the colors of the stars, or at least some color equivalent such as spectral type, must be known. These, alas, have all too often remained undetermined; and it is a distressing fact that extensive series of magnitudes, obtained at great expenditure of time and labor, can not now be reduced to the standard system without much added effort. As they stand, these magnitudes have little value, for they can not be combined with other data.

This state of affairs is not usually a mark of indifference on the part of observers, but rather of delayed recognition of the inherent complexity of the problem. Anyway, this is part of the truth. If early realization of the full meaning of magnitude would have been a hindrance to the ancients, it is equally true that the comparatively recent physical formulation of the problem accounts for much wasted effort. We seem to be concerned with a case of arrested development; astronomers have become physicists only within recent decades.

Something else is to be said, however. Measurements of color always lag a stage behind measurements of brightness. The high sensitivity of photographic emulsions to blue and violet light permits the measurement of photographic magnitudes of stars whose visual or photovisual values are entirely beyond our powers. Moreover, photographic magnitudes, even without colors and consequently without reduction to a homogeneous system, could always serve some useful purpose; and so they were measured, extensively.

But this kind of usefulness is passing, and from the present confusion of photometric data this guiding precept stands clear: That no photometric investigation be undertaken which does not provide for the reduction of its results to the color system of the North Polar Sequence. Stars so faint that their color equivalents can not be determined should be observed only with instruments which give directly results on the international system. Since this system is defined by the ordinary silver-bromide emulsion used with the silvered reflector, and since the most powerful telescopes are reflectors, this demand does not seem excessive.

But you will immediately remind me that we are now in process of transforming all our silvered reflectors into aluminized mirrors. At first this promised to be a serious difficulty; but experiments at Mount Wilson have provided a simple solution. A filter of ordinary crown glass in front of the photographic plate transforms the aluminized mirror into the practical equivalent of a silvered reflector.

(9) Addressed to a Physicist

In the beginning I suggested that physicists have a way with questions. And now that you must hope I am getting near the end of things, some one will surely be ready with a last-chance query: But the total energy radiated by a star; what about that—doubtless to be expressed by some kind of a magnitude? And why be content with a crude spectral photometry that measures radiation at only two points in the spectrum?

Of course we have bolometers, radiometers and thermocouples, devices equally sensitive to radiation of all wave-lengths, and we do use them; but let it not be forgotten that you may take your telescope armed with one of these devices to the top of the highest mountain, point it at a star directly in the zenith, and still fall far short of measuring the total output of stellar energy, especially if the star be a hot one as stars go. The amazing performance of atmospheric ozone still goes on. Equivalent in amount to a thin shell only 3 or 4 millimeters thick at sea-level pressure, it still effectively blocks practically all radiation on the short-wave side of $0.29\,\mu$. At the other end of the spectrum the immigration restrictions are less stringent; and for those remarkable low-temperature stars —the long-period variables at minimum light—the total radiation that passes the guardian molecules of our atmosphere is a thousand times that transmitted by the visual region.

These so-called radiometric magnitudes are immensely important when we look at stars as individual physical machines, because they bring us a step closer to the total energy of radiation, an item undoubtedly of great significance, which by some mystery of notation we designate as the star's bolometric magnitude—a mystery because thermocouples, radiometers and bolometers all measure exactly the same thing. Further, by blocking out various sections of the radiation transmitted by the atmosphere, we obtain with these impartial receivers additional points on the spectral energy-curve of a star and thus learn more of another item of great physical significance.

A Utopia of intellectual and instrumental accomplishment would, I suppose, include the bolometric magnitude and a complete spectral photometry for every star we know; but we do not get very far on the way toward either of these ideals. The part of a star's energy that we catch on our pin-point earth is too slight to stir the impartial recorder far out of its comparative sluggishness, and for all but the brightest stars will stand none of the dilution essential for any proper spectral photometry.

The astronomer, like the physicist, wishes to know about stars as atomic machines; but, impressed by the fact that there is more than one star in the heavens, he has also a mind full of questions about the numbers of stars of each degree of brightness and how they group themselves into systems and a system of systems extending endlessly outward into space. So he works his thermocouple and does his spectral photometry when possible, then compromises upon magnitudes which give, at the same time, measures of color, and hence a little knowledge of physical states; but, finally, for those objects so faint as to be caught only by the tip of the sensitivity curve of his photographic plate he must be content with a magnitude which tells him nothing of stellar conditions but remains a colorless datum to be fed into formulae for distances and distribution that he may learn at least something about the amazing universe of the telescope.

SCIENTIFIC EVENTS

THE VIRGIN PORT ORFORD CEDAR TRACT RESERVATION

Eleven hundred acres of virgin Port Orford cedar timber have been proclaimed a "Natural Area" by order of F. A. Silcox, chief of the U. S. Forest Service, to be kept forever in its pristine condition. This area lies within the Port Orford Cedar Experimental Forest on the South Fork of the Coquille River, which