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MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

THE AIMS OF AN ASTRONOMER.¹

Two titles have suggested themselves for my address of this morning, 'The Aims of a Man of Science' and 'The Aims of an Astronomer.' The objections to the more restricted title are, that those of you who do not know me might think that I was about to discourse upon the inhabitants of Mars, or give you a technical paper interspersed with mathematical formulæ of appalling length. From both of these courses I solemnly promise to abstain. The broader title might lead me into domains outside of my own studies, which are always particularly tempting to a specialist. The early aims of an astronomer must be passed over briefly to reach the more alluring field when they become, or should become, the aims of astronomy.

The first aim of a boy when he reaches manhood, and becomes an independent unit in the community, is generally to acquire money or its equivalent. This aim for a time is perfectly legitimate. He is entitled to support, food, lodging and clothing. Unfortunately, the savage has here a great advantage over civilized man. As soon as he attains his full strength and physical development, he becomes an important member of his tribe. He can hunt and fish, and can live in even greater comfort than his elders. The complex wants of civilization have changed all this. With us, a boy must get his education, and for years must be dependent on others when he should

¹Address before the Harvard Chapter of Phi Beta Kappa.

be self-supporting. Many of the evils of socialism, hatred of the rich and fear of powerful organizations, are due to this cause.

If a man never gets beyond the money-making stage, he can hardly be called a student of science. Let us assume that he is intellectually a success and attains a college position. He will never be rich, but since he is as well off as his associates he is not poor. His next aim is likely to be personal fame—a better object than wealth, but still a purely selfish one. In this stage of his development he tries to obtain honorary membership in societies, degrees or other honors, instead of waiting for them to come to him unsolicited. He makes reclamations of priority, and deposits sealed packages in the safe of the French Academy, so that if any one else should make the same discovery he can call for his package and prove that he is entitled to the entire credit, since he was first. If he is young, he attacks the work of some older man, and thus gains notoriety, even if his charges are disproved or ignored. The specious plea, 'I feel obliged, in the interests of science, to point out that my friend, Mr. A., is entirely wrong,' seldom conceals the true motive.

The next aim is higher and is for fame, not for himself but for his college, his city or his country. Enthusiasm for his state is dampened when the latter attempts to tax scientific institutions, instead of aiding them as is done in all other civilized countries. For years nearly all English mathematicians, following Newton, dealt with fluents and fluxions, while the continental mathematicians, following Leibnitz, used differential coefficients. The astronomers who gave the principal credit to Adams for the discovery of Neptune were nearly all Englishmen, while few Frenchmen admitted the claims of any one but Le Verrier.

This brings us to what should be the true aim of the student of science, the advance-

ment of human knowledge and the determination of the laws regulating the physical universe. His sole object should be to secure the best possible results, and he must be ready to make any sacrifice of his personal wishes for this end. Astronomy thus becomes international, and wholly impersonal. To how many of us is this the one and only aim, regardless of all selfish considerations? We must not expect too much of poor human nature, and yet it can do no harm to make our ideal a high one. No man is likely to surpass his ideal, and even if it is so high that he can not hope to reach it, he may go further than if he tries only to attain money or fame. The aims of the astronomer thus become the aims of astronomy, and there is no subject to which he can better give careful attention.

No man can hope to advance science now, as has been done in the past. Think of writing a book which not only would survive and be useful for two thousand years, but which for fourteen centuries should be the great work, and practically the only authority, of its kind. Yet this is the position held by the *Almagest* of Ptolemy. During the greater portion of this time it was reproduced again and again by laborious hand-made copies into which errors crept, were repeated and multiplied. By far the best copy bridges more than half the interval, since it was clearly written in the uncial characters of the ninth century. It is deposited in the *Bibliothèque Nationale* in Paris, and in 1883 was kept in one of the show cases of that institution. It contains a catalogue of more than a thousand stars, which is perhaps that prepared by Hipparchus, nearly two centuries earlier. It not only gives the positions, but the brightness, of all of these stars, and shows that at the beginning of the Christian era the appearance of the heavens was nearly the same as at present. Even a careful observer, without instruments,

would have difficulty in detecting any differences during these two thousand years.

But for the errors in copying mentioned above, the *Almagest* would still give us valuable information regarding the secular changes in the stars. No worker in science knows whether his results will have any value a century hence. The work of the older astrologers was supposed, at that time, to be as valuable as that of the astronomers. No one could tell that the work of the early chemists was of more importance than that of the alchemists. Until within a century, the estimates of the light of the stars as given in the *Almagest* were considered as of little scientific value. One man of genius, Sir William Herschel, recognized the value of accurate determinations of stellar brightness, and from 1796 to 1799 he published four catalogues of 1,905 stars, covering two thirds of the northern sky. It was my great good fortune, when visiting his grandson in 1883, to discover the manuscript of two other catalogues, which when published rendered the work complete for the entire portion of the sky visible in England. For eighty years they had lain on the shelf, unknown to astronomers, and their existence was not even suspected. Although the observations had been made with the greatest care, the six catalogues were not in a form that could be used. The necessary reductions and publications of the results were made at the Harvard Observatory, and thus we were enabled to present to astronomers a catalogue of nearly three thousand stars, showing their brightness a century ago and determined with an accuracy which has only been equaled within the last few years.

These are examples of great successes by clear-sighted men of genius who little suspected how highly their work would be appreciated after they were dead. To offset this, there are whole generations of astron-

omers whose life work is now of little or no value. Let each man ask himself to which class his own work belongs. Only the future can decide with certainty, but we can at least improve methods, which will certainly do good and can do no harm.

Unfortunately, astronomical research has now become so expensive that large sums are required to carry it a step beyond what has already been accomplished. A word must, therefore, be said to men and women of wealth who desire to aid this science by gift. Many persons have learned how to accumulate great fortunes, but few have succeeded in giving away wisely large sums of money for scientific work of the highest grade. It is strange that a shrewd business man, who by life-long labor has accumulated a fortune, if he wishes to give it away, should not use the same skill that he did in acquiring it. When buying a mine he sends experts to examine it, and assures himself that he will obtain an adequate return. When converting his money into scientific results he should similarly satisfy himself that his plan is a good one, and that it will fill a real want.

Let us, therefore, hereafter have no needless duplication of observatories, no great telescopes that are idle, no costly expeditions which, owing to insufficient preparation and lack of proper organization, will surely bring no adequate return. Money placed in the hands of a suitable committee would doubtless be spent to great advantage. The Rumford Fund of the American Academy and the Elizabeth Thompson Fund are thus well and wisely administered. But it is pitiful to hear from men of the greatest ability their needs for apparatus, assistants, or means for publication, which can not be supplied by the few hundred dollars thus available.

One of the greatest needs of the physical sciences at the present time is a liberal fund for research, administered solely in

the interests of science, and by scientific men. Some of the members of such a committee should be active workers in science, some of them older investigators, still able to advise and judge, but lacking the energy of youth required to undertake research themselves. We have striking examples around us, even in this gathering, of suitable men who have passed the usual age of retirement. Some of them are still so active that they appear to accomplish even more than when they were younger. A fixed age of compulsory retirement sometimes leads to curious results. A Washington astronomer, when retired ten years ago, had all his work taken away from him and was not allowed to complete it, even at his own expense. His life is still full of work and original suggestions. An army engineer from Cambridge, too old to serve the government, has been for years, since his retirement, engaged in the greatest problems of his profession, including the Panama Canal. The thanks of Congress lengthens a man's professional career by ten years. An admiral came near having his usefulness prolonged for four years, since he was so fortunate as to be born on the twenty-ninth of February. One of the greatest and most active of living astronomers will soon be retired just as he has completed and has ready for his use the most perfect apparatus yet contrived for measuring the places of the stars. When the plan for compulsory retirement was introduced at Harvard I hoped that the observatory might profit by it. Any man can complete his own work much more economically than another. I pointed out that at the observatory we had much unfinished work, the time for my retirement was approaching, and I suggested that an appropriation should be made at once to complete it. The time is now much shorter, the work is still unfinished, and the appropriation has not yet been made.

A committee constituted as described above, and having liberal funds at their command, could advance astronomy in several different ways. My sympathy goes out to the young man who has taken a post-graduate course in astronomy, has studied abroad at a great and active observatory, and comes home to teach in a little country college. He wishes to continue his work in astronomical research with the new instruments and by the same methods he has just learned. His college has no money for such purposes, his associates do not sympathize with his wishes, and his time and strength are fully occupied with instruction. He writes a pathetic letter stating that if he had only a few hundred dollars for a certain instrument he would gladly give his own time to the proposed work. Last month I received a letter from a Jesuit priest in Buluwayo, a thousand miles from the civilization of Capetown, giving me certain definite meteorological facts resulting from a year's careful observation in that wonderful climate. He described some important observations he wished to make if he only had five hundred dollars to purchase a mounting for his telescope. The committee would not only give such a man the required aid, but also the encouragement which is often still more highly prized. The man of genius is, in many cases, sensitive, retiring, unable to promise results, or to make known his needs. He must be sought, treated with tact and encouraged. If transplanted to other surroundings, or even if supplied with better appliances, his usefulness may cease. No amount of organization would help him, in fact any interference with his plans is likely to spoil them.

On the other hand, a great observatory should be as carefully organized and administered as a great railroad. Every expenditure should be watched, every real improvement introduced, advice from ex-

perts welcomed and, if good, followed, and every care taken to secure the greatest possible output for every dollar expended. A large part of the income is used for salaries, heating, lighting and repairs. Accordingly, a small increase in the resources will produce a disproportionate increase in the scientific results obtained. Much of the work of a large observatory is routine, studying thousands of stars in the same way, the work extending, in some cases, over many years. A great saving may be effected by employing unskilled and therefore inexpensive labor, of course under careful supervision. In this way a great increase in the results can be obtained from a moderate expenditure, and the amount can be closely estimated in advance.

The clerical work is largely copying numbers on prearranged forms, and computing in which only a knowledge of the four rules of arithmetic is needed. Such work must always be checked by an experienced assistant, and all errors detected by duplicate or triplicate computations. For such routine work we pay from twenty-five to thirty cents an hour, which is much above commercial rates for similar work. Prices are much lower in Europe, and supervision would also be cheaper there. An exhibition of wood-carving and embroidery has recently been held in Berlin. Some beautiful specimens were shown which had been paid for at the rate of half a cent to three cents an hour. Less skill would be required for much of the routine work needed in an observatory. If Asiatic labor could be employed, the prices would be still less, although the cost of supervision would be greater. In India, when tiger-hunting, the beaters go into the jungle armed only with a tin pan, which they beat violently with a stick. They thus frighten the tiger and chase him towards the tree in the top of which the bold hunter is safely seated, armed with a rifle. The beaters are

paid the liberal sum of three to four cents a day, which is increased to six cents if the work is done properly and the tiger is killed. The family of the beater would probably prefer that he should engage in almost any department of astronomical research. The most savage despotism of modern times was overthrown, and peace and comfort brought for the first time to the millions of inhabitants of Central Africa, by soldiers, the greater portion of whom were paid at the rate of five cents a day.

It is not unusual for the unsuccessful to criticize those who are richer and more powerful than themselves. In some countries this is done with the aid of dynamite bombs. In others (I mention no names) it takes the form of newspaper attacks on wealthy men, corporations, trusts, insurance companies and railroads. When we begrudge the hundreds of millions acquired by Standard Oil, should we not remember how much of it was earned by the genius of the men who evolved the most perfect business organization the world has ever known? If we say that Mr. Carnegie ought to distribute his millions among his workmen, let us recall the fact that he was able to sell three pounds of steel for two cents, by giving to the Bethlehem Steel Works an administration and management of every detail, superior to that of any similar corporation in existence. A great railway system may misuse a large sum of money, and yet this is a trifle compared with the thousands of millions of dollars it brings to the country by supporting a vast community of farmers who are enabled by its aid to send the products of their farms to the markets of the world. If we apply these principles to astronomy we may expect the same advance that has been accomplished in commerce, agriculture and manufacture.

Who would object to a trust whose sole

objects would be increased production, reduced cost to the public, and no profit to those forming it? The advantages of careful administration in scientific work are illustrated in a plan I detailed at the Franklin bicentenary, a few weeks ago. A telescope of the largest size entails great expense, but might produce a collection of photographs which would furnish useful material for study to half the astronomers of the world. My plan proposed that a reflecting telescope of seven feet aperture should be mounted in the best possible location, probably in South Africa, and kept at work photographing the sky throughout every clear night. An international committee of astronomers would decide to what special work the instrument should be devoted, and the photographs, or copies of them, would be distributed throughout the world to any astronomers who would make proper use of them. Copies of any or all of the photographs would be sold at cost to whoever wished for them. An astronomer of any country, prepared to undertake a particular research, would be furnished with the best photographic material that could be obtained in the present condition of science. Means would also be provided him for making suitable measurements, for reduction of the results, and finally for publication. Any competent astronomer, however isolated, would thus be enabled to carry on his researches amid his own surroundings, as well as if he were at the greatest observatory in the world. The man best qualified to discuss the results often has very little skill, even if he has the time, to take the photographs. Conditions would thus be provided which would give the best results for each portion of the work, as in any well-organized industrial enterprise. The donor would be assured that he had supplied material for study for the most expert astronomers of all countries, instead of for those at a single insti-

tution. A careful estimate of the cost of carrying out this plan showed that it would be less than half a million dollars, or about one third of that of establishing an observatory of the first class, like those now existing.

The greatest problem of all for the committee to consider, and that which would really include all the others, would be to determine which departments of astronomy were being neglected, and which were receiving attention that could better be applied to other subjects. A committee without money could accomplish little, but if a moderate sum were placed at its disposal, with the promise of more if it were well expended, astronomical science might be lifted to a new and higher plane. Suppose the subject selected were double stars. Many men of genius have done excellent work with small telescopes and poor micrometers. Such men would be supplied with the best instruments they could use to advantage, and money for recorders, computers, and publication, if they desired it.

Various systematic examinations of all stars in certain regions, and brighter than a given magnitude, have been made for the discovery of new doubles. This work should be completed for the entire sky, both north and south, according to the same system, and with similar instruments and conditions. A certain minimum number of accurate measures should be obtained of all double stars. Computers of orbits complain that many important objects are neglected, while numerous superfluous observations are made of other less interesting pairs. The committee would communicate with observers, offering aid if they would supply this want. If not, owners of large telescopes would be asked to allow them to be used for this work, the committee furnishing the necessary micrometers and employing young astronomers as observers

who would get their training, if possible, from experienced specialists in this class of work. Computers of orbits would be aided in the same way, and their work might thus be greatly improved in quality and increased in quantity. Directors of observatories could get most valuable advice and help from the committee, and when a new observatory was established its plan for work could thus be greatly improved. The Harvard Observatory would gladly welcome and profit by such advice.

The committee should not stop with existing problems. When a new line of research, like measuring the heat of the stars, is proposed, they should at once investigate it and, if the results are promising, test it. If it prove successful, they should carry it as far as present means permit. In this, as in securing the cooperation of existing observatories for any of the great problems now before us, there seems to be no limit to the results obtainable by a wise administration.

The donor, as well as the astronomer, must be asked to consider first the interests of science. His name would necessarily always be associated with his gift, and would he not prefer a world-wide, to a local, immortality? There must now be many wealthy men trying to find some good use for the money they can not take with them out of this life. The hardest problem will be to find an active committee with no taint of selfishness. This taint exists even among astronomers. There is no more permanent, economical and efficient trustee than a great university with long continued and honorable traditions. As with any other wish of the donor, it could secure and enforce unselfish management, as well as efficiency.

Industrial enterprises half a century ago were in nearly the same condition that science is in to-day. May we not expect in astronomy the same advance by coopera-

tion and organization? If donors, trustees and astronomers can thus be led to work for scientific results alone, regardless of country or personal considerations, it will be the best return I can make for the great privilege of addressing the Harvard Chapter of Phi Beta Kappa.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY.

SOME ASPECTS OF THE PANAMA CANAL.¹

AFTER approximately six years of investigation, the selection of both route and type for a ship canal across the Isthmus of Panama is nearly completed. Although the report of the board of consulting engineers already made public is not final, it leads to the final consideration of the question in congress so that on the conclusion of congressional consideration work can be promptly begun under the adopted plan. Whether the final plan be that of a lock or a sea-level canal, the route will be the same, practically that of the Panama Railroad running between Colon on the Caribbean side of the isthmus and a point called La Boca on the Pacific side, a mile and a half west of the city of Panama.

The length of the Panama Canal is about 49 miles between 40-foot contours at low water at its termini, but the length between shore lines will be not more than 42 miles.

The topography of the Isthmus at the Panama crossing is well adapted to the construction of this ship canal, the original summit of the divide on the line of the canal being but about 330 feet above sea level. This has now been reduced to about 170 feet above mean sea level by the French excavation at Culebra. About one half of the length of the canal lies along low marshy ground on either side of the

¹Read at the Ithaca, N. Y., meeting of the American Association for the Advancement of Science, June 30, 1906, before Section D, Mechanical Science and Engineering.