The Great Star Map—I*

The Team Work of the World's Astronomers

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The simpler name "star map" is here applied to the chart generally known as the "Astrographic Chart," because this latter conveys a suggestion of technicality which is absent from the project. What astronomers in different parts of the world are really about is the making of a large and much more detailed map of the stars than has hitherto been produced. The map is being made by photography; but though the word "astrographic" has been coined for use when photography is applied to the stars, the work does not involve much technicality that is not familiar to the users of an ordinary Kodak. In three details only does the work of the astronomer differ from that of the amateur photographer: he uses a much longer camera; he drives the camera by clockwork so that it may follow the stars; and he takes pictures at night instead of in the daytime. It may perhaps be added that he uses the light emitted by stars, instead of photographing objects by reflected light of the sun. But of these details more presently.

Let us first consider what is the nature of a map of the stars, as this differs somewhat in character from the maps of the earth's surface with which we are familiar. There is no question of finding our way, no question of delimiting property, no question of showing hills and valleys. A map of the stars is of a more monotonous character, being practically limited to showing the exact positions and the brightnesses of individual points of light. Maps of the stars may differ from one another in scale, in accuracy, and in completeness: In scale because we may show two given stars separated on the map either by a foot or by an inch, according to requirements; accuracy will have a tendency to be greater on the larger scale; and they may indicate either a few bright stars or many faint ones. We are familiar with the fact that there are only a few very bright stars, more of a degree less bright, more still fainter stars; and the increase continues as the luminosity diminishes, long after they have ceased to be visible to our eyes, no limit being reached even by the longest exposures given with our largest telescopes. Completeness then can only be a relative term. It is at present impossible to think of giving all the stars in the sky; we can only settle to give all those brighter than a certain fixed standard.

The earliest maps of the stars were probably made for astrological purposes; later they were required for the use of sailors. But through all the centuries so little had been done towards making accurate maps that in 1674, when there arose a question of finding the longitude at sea by observations of the moon and stars, it was pointed out by Flamsteed that no sufficiently accurate maps or catalogues of the stars were available. King Charles II., to whom this information was brought, was thoroughly alarmed at the state of affairs and immediately said that he must have the omission rectified. Thus was Greenwich Observatory established. When asked who was to take charge of the observatory, the king immediately replied that Flamsteed, who had pointed out the need of such an institution, was the man to put in charge. Modern observation of the positions of the stars may be said to have begun at this period. Greenwich took a great step forward half a century later, when Bradley was made the third Astronomer Royal and increased the accuracy of observation very considerably, so that his results have formed the basis of our knowledge of the positions of the stars to the present time. But Bradley and his successors for the most part confined their attention to the brighter stars, not concerning themselves with those much fainter than can be seen with the naked eye. There are two good reasons for this. In the first place, the number of stars required for the use of sailors is not large; indeed, sailors themselves use remarkably few, for only the brightest are suitable for observation by the small telescopes of their sextants. Indirectly, however, sailors depend upon the keeping of accurate time—Greenwich time is in use all the world over for determining longitude: and for keeping accurate time a much larger number of stars, called "clock stars," is required. These have had the first claim upon the attention of astronomers at our great observatories during a couple of centuries. A second reason for confining attention to these brighter stars arises from the limitations of instruments. The observations were generally made by watching the star cross the field of view, in which were certain spider lines for reference. Now these lines cannot be seen unless the field of view is illuminated, and a faint star is then lost in the illumination. In these days of electric light it is comparatively easy to adopt a new instrumental method, whereby the wires themselves (and not the background) are illuminated; they then appear as bright lines but are not sufficiently dazzling to obscure even a faint star, which can thus be observed as well as a bright one. But in former times this method had not been sufficiently developed and in any case the brighter stars were easier to observe. For these reasons therefore the fainter stars have not attracted attention until comparatively recently. One motive for studying them came with the discovery of the minor planets, which dates from the first day of the nineteenth century. It had been realized that there was a gap in the sequence of planets (as arranged in order of distance from the sun) between Mars and Jupiter. It was clear that there could not be any large planet in this position, for it would have been noticed; but there might be a small one, so search was made for it. The method of search was somewhat laborious. It was necessary to identify all the stars within a certain region in order that any strange body might be detected. It is now easy to accomplish this by taking a photograph of the region; but at the end of the eighteenth century no such compendious process was available; then the positions of individual stars were either patiently and laboriously measured one by one, or learned by the astronomer so that he could carry a picture of the region in his memory. In default of an actual material photograph he practically photographed the image on his own retina. It is astonishing to think how much was accomplished by this toilsome process. Not one only but hundreds of minor planets were discovered in this way, though not without difficulty and delay. Four were found at first in rapid succession and then came a long blank during nearly half a century, so that it seemed as though the number were complete: but though this view proved quite erroneous, it was only after a search of fifteen years that Hencke, an ex-postmaster of Driessen, was at last rewarded by another discovery. From that time the number has been extended almost continuously, so that we now know nearly seven hundred of these tiny bodies. From the circumstances attending the discovery and the subsequent observation of them has arisen one need for charting the places of the fainter stars. The easiest way to record the movements of these small bodies is to measure their distances from adjacent faint stars, and this is only satisfactory when we know the places of the stars themselves. This led astronomers to undertake the great work of charting the zone of the heavens called the Zodiac, in or near which all the planets move. Such an enterprise was started at Berlin early in the nineteenth century; another, initiated by Chacornac many years later was continued by the brothers Henry of Paris, who ultimately took the great step of employing photography in the work; and this led to the inception of the scheme we are now considering.

The introduction of the photographic method was at first fitful and tentative. Apparently the earliest attempts were made in America by the Bonds and by Rutherfurd. It is curious now to read of the difficulties in obtaining impressions of any but the brighter stars in the old days of wet plates. The wet plate of course was not nearly so sensitive as the dry plate; also it could only be exposed for a limited time before it dried up, and during such limited exposures only the brightest stars left an image upon it. Even the wildest hopes of these early pioneers in forecasting the future fell far short of what is now easily attainable: witness the following extract[1] from a letter of George Bond to the Hon. William Mitchell, Nantucket, dated from Cambridge (Mass.) July 6, 1857:

"As far as I am informed, the attempt to photograph the fixed stars by their own light has been made nowhere else up to the present date. The rumor of a daguerreotype of a nebula made in Italy some years since, was unfounded. . . .

"About seven years since (July 17, 1850) Mr. Whipple obtained daguerreotype impressions from the image of *a Lyræ* formed in the focus of the great equatorial and subsequently from *Castor*, thus establishing a simple but not uninteresting fact—the possibility of such an achievement. On these occasions a long exposure of one or two minutes was required before the plate was acted upon by the light. . . .

"Messrs. Whipple and Black recommenced their trials on other images (taken by the collodion process) in March of the present year and they are still in progress. . . . Could another step in advance be taken equal to that gained since 1850, the consequences could not fail of being of incalculable importance in astronomy. The same object *a Lyræ*, which in 1850 required 100^s to impart its image to the plate, and even then imperfectly, is now photographed *instantaneously* with a symmetrical disc fit for exact micrometer measurement. We then were confined to a dozen or two of the brightest stars whereas now we take all that are visible to the naked eye. Even from week to week we can distinguish decided progress. . . . At present the chief object of attention must be to improve the sensitiveness of the plates, to which I am assured by high authorities in chemistry there is scarcely any limit to be put in point of theory. Suppose we are able finally to obtain pictures of seventh magnitude stars. It is reasonable to suppose that on some lofty mountain and in a purer atmosphere we might, with the same telescope, include the eighth magnitude. To increase the size of the telescope threefold in aperture is a practicable thing if money can be found. This would increase the brightness of the stellar images, say eightfold, and we should be able then to photograph all the stars to the tenth and eleventh magnitude inclusive. There is nothing then so extravagant in predicting a future application of photography to stellar astronomy on a most magnificent scale.

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"P. S.—I find I have forgotten to allude to two important features in stellar photography—one is that the intensity and size of the images taken in connection with the length of time during which the plate has been exposed measures the relative magnitudes of the stars. The other point is that the measurements of distances and angles of position of the double stars from the plates, we have ascertained by many trials on our earliest impressions, to be as exact as the best micrometric work."

The letter is a remarkable one for the date. The three forecasts of improvement—increased sensitiveness in plates, larger instruments, and better climate—have all been realized within fifty years. There are two mountain observatories in California; there is a 40-inch lens, nearly three times the size of the 15-inch Harvard equatorial, at the Yerkes Observatory and two 5-foot mirrors represent an even greater advance; there has been also an enormous increase in sensitivness of plates. It was in this last particular that Bond failed to allow sufficient play to his imagination, as instead of an increase represented by one stellar magnitude we have more than ten times that estimate. But Bond's discernment was otherwise so great that this slight failure may be pardoned. His postscript shows that he realized even thus early the accuracy of the photographic method, and in this his judgment agreed with that of L. M. Rutherfurd, who set to work to measure his photographs systematically and soon found that they recorded the positions of the stars more accurately than his own apparatus would measure them. He used a micrometer screw and found, though he had provided himself with the best one available, that its errors were sufficiently large to prevent his doing justice to the photographs, and he turned aside from his original project to the construction of a better screw. Ultimately he made a screw so accurate that his attention was again distracted towards the completest possible test of its accuracy. This he found in the ruling of very fine lines close together on metal—several thousands within an inch—the result being what is called a grating, which can be used like a prism to spread out light into a spectrum. This work was so engrossing that Rutherfurd never seriously returned to his original purpose of measuring his photographs, but many of them have been measured since and have shown clearly how correct was his judgment of the accuracy of the photographic method. In spite of this accuracy, however, the inconvenience of the wet plate long delayed serious use of the method or the determination of star places. Photographs of the sun were taken showing the spots (requiring only a momentary exposure); measures of spot positions were made on these and found satisfactory. But a sun spot is an irregular object having no very definite position and does not afford a very severe test of accuracy; consequently this work failed to draw the attention of

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[1] Memorials of William Cranch Bond, Director of Harvard College Observatory 1840-59, and of his son George Phillips Bond, Director of the Harvard College Observatory 1859-65, by Edward S. Holden (Lemcke & Beuchner, New York, 1897), p. 155.

astronomers to the full resources at their command.

The complete change in attitude came in a rather sensational manner on the appearance of the great comet of 1882. This comet, which was a very respectable object in the Northern Hemisphere, was much more magnificent in the Southern. The dry plate had by this time made photography easy and many members of the public who had recently become possessors of cameras essayed to photograph the comet; they found to their disappointment that the rotation of the earth carrying them and their cameras with it was sufficient to spoil their pictures. Thereupon, Sir David Gill, then H.M. Astronomer at the Cape, invited one of them to come to the Observatory and to strap his camera to the equatorial telescope (which was fitted with clockwork to counteract the earth's motion); immediately some beautiful pictures of the comet were obtained, and not only of the comet but of the surrounding stars. The number of stars shown on the photographs was indeed striking, and attracted widespread attention. The late Dr. Common of Ealing, who had been constructing telescopes for himself, without however any definite intention of using them photographically, immediately turned them to this new purpose and obtained some beautiful pictures of nebulæ. The brothers Henry in Paris saw the possibility of substituting the new process for the immensely laborious method by which they had been making their ecliptic charts; but in their case the change could not be made so easily, as their telescope had been made for visual use and could not immediately be used photographically. The difficulty arises from the existence of numerous colors in white light, the colors with which we are familiar in the rainbow. When looking through a telescope with the eye we use chiefly rays nearly yellow in color, while the photographic plate is sensitive to blue and violet. Now a lens cannot be constructed to focus all these rays at the same time and consequently for photography a new lens must be made which will focus the blue and violet light instead of the yellow. There are ways of avoiding this difficulty which may be briefly mentioned. In the first place if we use a mirror which brings the rays to focus by reflection, instead of a lens which combines them by refraction, no color difficulty arises. (It was for this reason that Dr. Common was able to use at once for photography the reflecting telescope which he had originally built for eye observation.) Secondly, modern improvements in the construction of photographic plates have made them sensitive to yellow light under certain conditions, so that visual telescopes can be used to take photographs if a yellow screen cuts out the unfocussed blue rays, leaving only those for which the telescope has been properly focussed. When a suitable plate is then put behind the screen, pictures of the moon and stars can be and have been obtained quite as good as those obtained with a telescope specially made for photography. But in 1882 this had not been realized and the Brothers Henry saw no way of using the new and promising photographic method but to make a new lens specially adapted for it. This they set about with great skill and determination. After a few trials on small lenses they at last succeeded in producing a photographic lens of 13 inches aperture, a veritable triumph of optical workmanship at that time. They were of course amateurs at the work. Admiral Mouchez, the Director of the Paris Observatory, gave them every encouragement and put at their disposal such resources as he had available; but their workshop was after all a mere shed. I have often heard Dr. Common speak with amusement of his visit to the workshop which had turned out to the admiration of the world the first successful photographic refractor —the modest building and the humble appliances were so surprising. We are reminded of the simple appartus with which great experimenters like Faraday have often achieved the most remarkable results.

It was the work of the lens thus produced by the Henrys that led directly to the inception of the project we are considering. The specimen maps of small regions of the sky which they soon obtained suggested the possibility of producing such maps for the whole sky. The work contemplated was no child's play. At least 10,000 maps would be required to cover the whole sky; and a labor of this magnitude was beyond the resources of a single observatory. Correspondence between Sir David Gill—under whose direction the comet photographs had been taken—and Admiral Mouchez, who had encouraged the work of the Henrys, led ultimately to the assembling of a great international conference at Paris in 1887. It was a remarkable meeting, the first of its kind in the history of astronomy; and it has shown the way for subsequent gatherings which have already made their mark upon that history. Conferences of a similar kind have since been held in 1889, 1891, 1896, 1900; and after a long interval in 1909. On all these occasions the French have acted as hosts and have discharged these duties with a cordiality and hospitality that has never failed to impress their colleagues from the most distant parts of the world. It would be difficult indeed to imagine a more pleasing center for our meetings than Paris or a nation more admirably adapted to play the part of hosts than the French; and they have been rewarded by an increasing success in the gatherings. At the last meeting it became clear that the assembly had developed from a mere collection of those interested in a particular project into an organization of the world's resources for the promotion of the astronomy of position. The physical side of astronomy has recently been organized on somewhat similar lines (profiting no doubt by the example provided), and the existence of these two great organizations will have a notable effect in economizing our labors in the future. In 1887 such an important outcome was scarcely anticipated: Attention was then concentrated on the immediate task before the assembly, which was a difficult one in every way. Astronomers from distant quarters of the globe speaking different languages, none of them with much experience of photography or of its possibilities but most of them with opinions more or less formed, met together to try to secure unanimity, not only in generalities but equally in small details. We need not be surprised at some of the results. The discussions were, to say the least of it, animated. There are no universal rules for conducting such business and astronomers of one country were not familiar with rules in use elsewhere. It interested Englishmen, for instance, who are accustomed to have resolutions moved by any one rather than the chairman, to learn that this was by no means a universal rule. On the contrary, the chairman of the first conference considered it part of his duties to move all the resolutions. After listening to a discussion, he took it to be his function to summarize the sense of the meeting in a resolution which he put from the chair and in favor of which he held up his own hand. Unfortunately for his success his was sometimes the only hand held up and the discussion was necessarily resumed. Another feature of such discussions on the Continent is a little strange to our insular prejudices but might perhaps be adopted by us with advantage. Occasions sometimes arise when the collision of contrary opinions produces considerable heat and there is an obvious desire on the part of two gentlemen (or even more) to speak at the same time. On such occasions the chairman rings a bell and declares the sitting intermitted for a few minutes. What has been public discussion can now be developed as private conversation. Gentlemen of opposite views who have been addressing one another excitedly across the width of the room may now rush together and arrive at a better understanding at close quarters. The effect of such an opportunity soon becomes evident when after a few minutes' interval the chairman again rings his bell—a calm has succeeded to the storm and not infrequently it is possible to crystallize out a resolution.

Let us glance at one or two of the matters which had to be decided in 1887. The first and most important was the choice of an instrument or instruments—for it was a preliminary question whether the same pattern should be used by all those co-operating in the work. This preliminary question, however, was soon settled in the affirmative. All were to use similar instruments; and now what were they to be? Should they be reflecting telescopes as used by Dr. Common, refracting telescopes as made by the brothers Henry, or refracting telescopes of a different pattern and more closely similar to camera lenses as advocated by Prof. Pickering of Harvard?

The advantages of the reflector were that it was cheap and that it existed. It is cheap because there is only one surface to be polished. Reflectors used to be made of speculum metal polished to a concave form; such were, for example, the great telescopes of Sir William Herschel and of Lord Rosse: nowadays instead of metal we use glass silvered on the face (not on the back as in a domestic looking-glass): but in either case there is only one surface to be prepared optically. Now with lenses there are two, four, or even more surfaces, all of which must be optically true. Moreover the glass must be entirely free from blemishes; if there is a fault in the substance of the glass which forms a mirror it is behind the reflecting surface and may not spoil the image but a fault in the interior of a lens cannot fail to produce its effect. Hence a lens is always much more costly than a mirror of the same size and the greatest telescopes in the world have always been reflecting telescopes. Lord Rosse's 6-foot mirror has not yet been surpassed in size, although Dr. Common and Dr. Richey have both succeeded in making mirrors of 5 feet and a mirror of no less than 8½ feet diameter is proposed, but the largest *lens* in the world is the Yerkes of 40 inches. Hence it could not fail to impress the conference of 1887 that the more economical instrument would be a reflector; moreover several such reflectors were already in existence and could, so it was hoped, be utilized without further expense. Thus at Oxford there was a reflecting telescope, which Dr. De la Rue had presented to the University Observatory, with which Prof. Pritchard hoped to take a share in the great project: If it were decided to use a different pattern of instrument his hopes would be disappointed unless he could obtain the money necessary to purchase one of the adopted pattern.

As regards the two forms of refracting telescope, the refractor and the doublet, that advocated by Prof. Pickering was the more expensive and the less known. In the light of our modern knowledge of its advantages (especially for the purpose of covering a larger area of the sky at once) it is very strange to find so little in support of it in the accounts of the discussion. It seems to have been put aside almost at once, in spite of the letter urging its adoption from Prof. Pickering. The chief reason for this was undoubtedly lack of information as to the accuracy with which plates taken by such an instrument would give the places of the stars. Specimen photographs taken by the brothers Henry with the other form of refractor had been measured and shown to be very satisfactory, but there was no corresponding information about the "doublet" as this third form of instrument is now usually called. Hence the doublet was put aside from the start and the choice was made between the reflector and the simple refractor.

The decision fell upon the latter. The choice has proved to be a wise one and it is satisfactory to remember that it was made without any acrimonious discussion. This was largely due to Dr. Common himself, who might perhaps have been expected to lay stress on the particular advantages of his own special instrument. His experience however had impressed him rather with its defects, especially with its uncertainty. This uncertainty is not due to the instrument itself so much as to our fitful climate: The reflector is so seriously influenced at times by air currents and changes of temperature as to be an instrument of moods and Dr. Common has accordingly compared it, somewhat ungallantly, to the female sex. He himself took the initiative in recognizing that the Conference should adopt for a work of such magnitude the more trustworthy refractor as made by the brothers Henry; this straightforward course had its due effect on the formulation of a decision. There are now therefore a score of such instruments scattered about the world, varying a little in non-essentials but all closely resembling one another in the size of the lens (which is 13½ inches in diameter) and in the focal length of the telescope (which is about 11½ feet). The focal length is actually defined to be that which represents one minute of arc by a millimeter on the photographic plate; and this relation is so useful that in cases where a larger telescope has been built, the relationship has been recognized by making the scale exactly twice the size. Dr. Common adopted the same focal length (of about 11 feet 6 inches) for his excellent mirrors of 30 inches aperture; with these recently the beautiful photographs of comets have been taken and their power of discovering faint satellites has also been shown.

Another very important decision taken by the Conference of 1887 had a rather curious history. It arose from the ignorance, at that time, of the behavior of a photographic film and the fear lest it should shrink in drying or otherwise become distorted. Experience of photography generally—as for instance the taking of portraits or landscapes—was sufficient to show that such distortion was at any rate not large; but in astronomy we are concerned with very minute quantities and it was not known whether minute disturbances might not affect the relative positions of the images on the plate. Accordingly it was proposed to imprint upon each plate a series of accurately ruled crosslines called a *reseau*. They were to be photographed on the plate before development by exposing it to an artificial light behind a silver matrix (a flat plate coated with silver ruled with such lines); on development the lines appear together with the star images and if the film has shrunk during any of the processes of development, fixing, washing, etc., these lines will have shrunk sympathetically and will be no longer straight or at exactly equal distances as they were in the matrix. We have now learned that such shrinkage is so very small as to be negligible, at any rate for the purposes of our star map; indeed, even in the most minute investigations it is easier to neglect the shrinkage as accidental in character than to investigate it. Accidental errors can be obviated by taking another plate (or a number of other plates) and so far as our present experience goes the whole series of plates is very unlikely to be affected by any common or systematic error. Hence the function assigned to the *reseau* was due to a misapprehension and it has never been used for the purpose originally proposed. Fortunately it has been of immense value in another way. The lines have served as reference marks in determining the places of the stars with facility. To measure the distance between one image and another we might have used a long screw to carry a microscope from one to the other, but it is better to compare the distance with a standard scale, using a screw to connect the stars with the ends of the scale; the latter method is to be preferred because it avoids the use of a great length of screw. Screws can now be made very accurately if necessary; Rutherfurd's work laid the foundations of such accuracy. But they are costly; their use over a large range takes time in turning the screw through many revolutions; and continual use is apt to wear away the screw and render it no longer accurate. Hence it is preferable to use the method of comparing with a scale; the *reseau* has practically supplied an accurate scale in both directions for the rapid measurement of star positions on the plate.

We may pause here to remark that the term "map" when applied to the present project must be used in a rather comprehensive sense. The scheme includes not only the pictorial representations on the plates or on any prints made from them but also the measurement of these plates and the publication of the measures of the individual stars. We can if preferred use a descriptive name for these measures. The printed books containing them are often called the Astrographic Catalogue as opposed to the prints which are the Astrographic Chart proper; but the whole project is really one and the same, although the usual process adopted in making a terrestrial map is here inverted. Surveyors of the face of the earth make careful measurements first and then plot them on a map and that was the method of astronomers before the days of photography. Now, however, we first take photographs and then measure them; but the project would be incomplete without full measures and charts. An illustration may be given of the risk involved in using one of these methods alone from the practice of Egyptian surveyors. They have been accustomed by centuries of tradition to enter their measurements of land in books without proceeding to make a map. It is only within the last few years that the Egyptian survey under Captain Lyons made maps for the first time of the landed property in Egypt; and when these beautiful maps were exhibited in Cairo thousands of landowners saw their property thus represented for the first time. When the maps came to be made the disadvantages of the old plan soon became apparent; some pieces of land had been recorded twice over while others had been omitted altogether. We can readily understand how this can happen in mere numerical records, though it is not so easy to understand how some individuals became reconciled to pay taxes as an annual consequence twice over; that some should have failed to resent their escape from taxes altogether is more intelligible.

(*To be continued*)

Practical Aspects of Printing Telegraphy—VI*

An Inventor on the Difficulties to be Encountered and the Way to Overcome Them

By Donald Murray, M.A.

Continued from Supplement No. 1860, page 135

KEYBOARDS AND KEYBOARD OPERATING.

With code and cipher messages it is absolutely essential that the operator shall keep his eyes fixed on the message all the time that he is sending, if he is to work rapidly and accurately. With the Morse key and sounder it is an easy matter for an operator to keep his eyes on the copy. With a typewriter keyboard, on the other hand, it would appear at first glance to be very difficult to work without looking at the keyboard. Experience has shown, however, that there is no real difficulty, and that in one month, with proper training, an operator can become an expert in "touch writing" on a typewriter keyboard. That is to say, he can learn within a month to operate rapidly and accurately on a typewriter keyboard without taking his eyes off the message. Code and cipher messages are then as easy to transmit on typewriter keyboards as on the Morse key, with the advantage that a single stroke on a key sends each character.

The same difficulty has been experienced in connection with the use of the ordinary typewriter in telegraphy, and also in using certain Morse transmitting keyboard machines. The typewriter companies long ago discovered the value of "typewriting by touch," and all the record breaking "typists" work in that way. Linotype operators have also discovered the advantage of this method of working. Some years ago it was noticed in New York newspaper offices that certain linotype operators (on piecework) were making considerably higher wages than their fellows. It was discovered that they had learned to operate the very large and complicated linotype keyboard of ninety characters without taking their eyes off the copy. Knowledge of the method soon spread, and "touch operating" on linotypes is now quite general. Typewriter keyboards are much less formidable. On the piano, of course, playing by touch is essential, and it is much more difficult than on a typewriter. On the latter it is merely a question of systematic instruction and training on the lines long ago found necessary in piano playing.

After some months' practice in this way, operators become extremely rapid and accurate. The author has seen 101 successive average British messages of 20 words perforated on a keyboard without a solitary error, and that at the high speed of 90 messages an hour. This is over 2,000 words per hour of complicated matter with many figures and strange words and addresses and personal names. The operator had at the same time to sign the messages and number the perforated tape.

The best operators are those whose sending becomes purely mechanical. Some men will use the Morse key and talk to you at the same time without making a mistake in the message they are sending. Others can whistle a tune and keep time with the "sticks," while punching a message on the Wheatstone puncher, and the perforated message will be free from errors. Operators have been known to work for a whole day on the Morse key without making a single mistake. When this stage of automatic perfection has been reached the operator becomes valuable, especially in the case of printing telegraphs. Such skill reduces the number of errors and of corrections and inquiries, and it is these corrections and inquiries that reduce the output of a telegraph system so much. Every such correction or inquiry means a loss of time on the average equal to the time of transmitting half a message, and more in those cases where the sending operator has to stop to look up the previous message to answer the inquiry. As an illustration of how automatic the work of sending messages becomes, a case was mentioned in the *Telegraph Age* of an operator

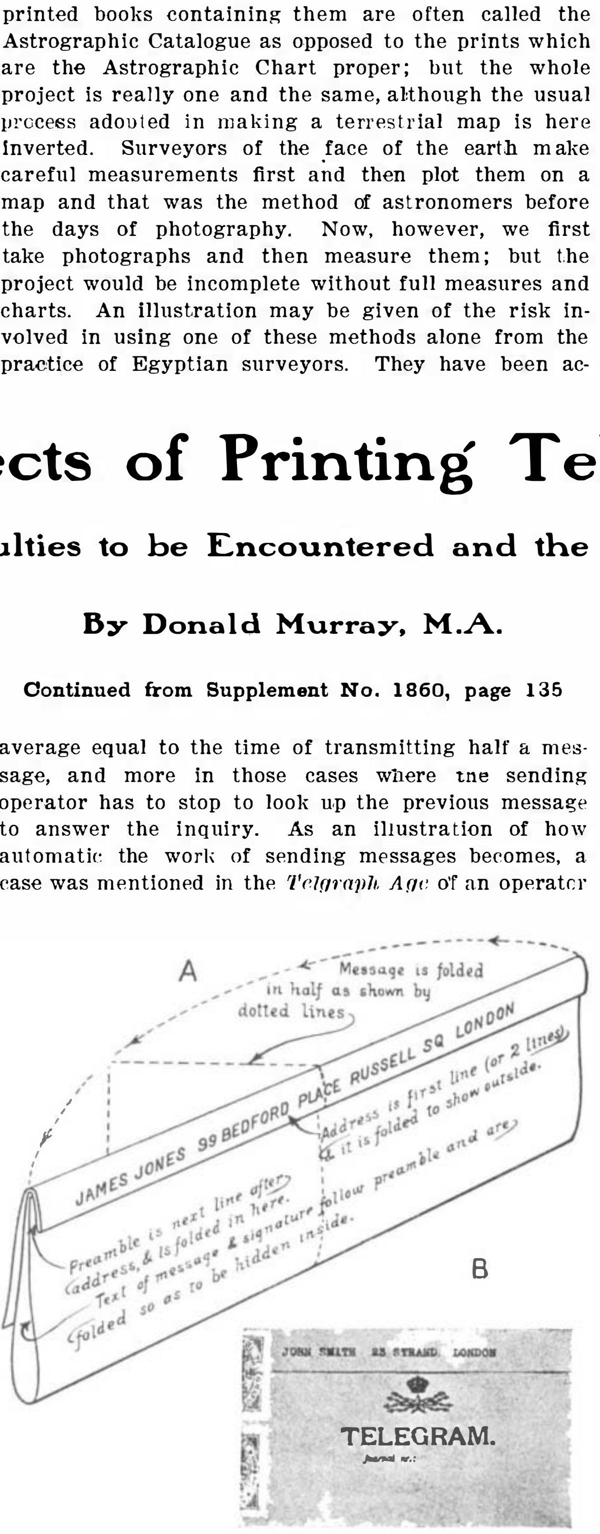

Fig. 3.—*A* Shows the Murray Printing Telegraph Method of Folding Telegrams so as to Dispense With Envelope. *B* Shows a Message Completely Folded and Sealed With a Couple of Adhesive Telegraph Stamps Used for This Purpose Only. The Advantages are Saving of Cost of Envelopes and Saving of the Time and Labor of Addressing Them.

in an American telegraph office having received the news of Lincoln's assassination over his wire without noticing it. He wrote it out and the news was posted up outside the telegraph office. A great crowd assembled. The telegraph operators were surprised, and on inquiring what the crowd was about learned that Lincoln was shot. The operator who had received the message, had received it mechanically, and had been entirely unconscious of the substance of the telegram he had written down. That sounds incredible, but it is no surprise to telegraph operators, and it is no surprise to highly skilled shorthand writers. It is exactly in accord with their own experience.

CONTRACTIONS.

With the Morse key an operator can use contractions in sending, because the receiving operator can easily write out the words fully on a typewriter. In the case of a printing telegraph this cannot be done, and if a word is sent over the line in a contracted form it will be printed in the same way. In America contractions are very freely used by operators, and these contractions have presented some slight difficulties to printing telegraph inventors in the United States. In Press messages contractions are also very freely used, and in Press messages to be sent over long ocean cables contractions have been developed into a fine art. All that a printing telegraph can do in such circumstances is to record the contractions.

ENVELOPES AND ADDRESSES.

On the Continent of Europe telegrams are not put in envelopes. They are folded and sealed and sent out in that way. In Germany the address has to be inserted in a special place in the middle of the top of the form. As the preamble comes before the address (in accordance with the terms of the International Telegraph Convention), the preamble has to be printed first, then the address, in Germany, above it, and afterward the text below it. With a tape printing telegraph like the Hughes, it is easy to put the address at the top, or on the back as in France; but with a page printing telegraph, if it is to work automatically, there cannot be any turning back to put the address in the middle of the top of the message form, and it is quite impossible to print the address on the back as required in France. Fortunately, in the case of the Murray automatic system as there is a receiving tape on which the message is recorded as perforations before it is printed, there is no difficulty in turning back by hand and printing the address where wanted, without interfering with the reception of the signals over the line. This is the arrangement adopted in Germany with the Murray automatic system, but there is undoubtedly loss of time when the automatic line and page feeds are not fully employed. In any case with a direct-printing page-printer turning back is not possible, and the message must be printed straight ahead as received. Page-printing saves time and labor; but the use of envelopes has a number of drawbacks. With the message folded so as to show the address only, as on the Continent, no envelope is needed, and therefore there is no loss of time and labor in addressing the envelopes and there is no risk of error in copying the addresses on the envelopes. Also the cost of envelopes is a considerable item. In Great Britain, for instance, 90 million envelopes are required for telegrams every year. Doing without envelopes would therefore save a considerable sum; but in Great Britain there are a large number of registered addresses, and these compel the writing out of the full address. In many cases, though, the more important registered addresses are printed ready on envelopes. The author devised a method of folding messages to suit page-printing telegraphs (see Fig. 3).

In this arrangement the address is transmitted first and then the preamble. This gets rid of any necessity to turn back, and the message can then be folded so as to show the address only. The conditions, however, are very complicated and in a case of this kind where there are so many conflicting considerations government departments are slow to move. Up to the present the new system of folding has not been used in England or Germany, but it is used in connection with the Murray automatic system in Russia, Sweden, and Norway. It is suitable for any page-printing telegraph, and it appears to be the only possible way of doing without an envelope in the case of messages received on a direct-printing page-printing telegraph.

MECHANICAL DIFFICULTIES.

This record of printing telegraph troubles may be conveniently brought to a close by some reference to the mechanical difficulties arising from the special mechanical problems that have to be solved by the inventors of printing telegraph machinery. Telegraph instruments belong to the class of controlling machines which are of necessity composed of locks, valves, and other ratchet mechanisms. These are the most unsatisfactory of all the kinematical elements, because they do not slide or roll; they strike. Also, their bad character is not improved by the facts that

* Paper read before the Institute of Electrical Engineers.