EXERCISES IN ASTRONOMY

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REVISED AND EXTENDED EDITION OF
''PRACTICAL WORK IN ELEMENTARY ASTRONOMY''
BY M.G.J. MINNAERT

Edited by

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Elementary Astronomy' by M. G. J. Minnaert

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EDITOR'S PREFACE

"I hear and I forget,
I see and I remember,
I do and I understand."
(Chinese proverb)

Students get a deeper understanding of a subject by a concentrated involvement in it. "One learns astronomy best by doing it" or "Learning astronomy by getting one's fingers dirty" — such was the philosophy of astronomy learning of Professor Minnaert. He contributed much to astronomy teaching. The first edition of his book "Practical Work in Elementary Astronomy" (published by D. Reidel 1969) emphasized classical astronomy and was intended for students of physics following their first course of astronomy. The book was much favoured by students and teachers of physics and astronomy in many countries. It has been long out of print and a new edition was often asked for.

Professor M. G. J. MINNAERT was a renowned scientist, eminent teacher and a great personality. To prepare a new edition of his Exercises was not an easy task for me. Therefore I asked my friends for advice and help.

My thanks are due to those colleagues whose exercises are included in this new edition. I apologize to all those whose contributions are not included. It was with great regret and hesitation when I laid aside their original and often excellent exercises.

The variety of subjects treated in the added exercises and the multiformity of astronomy teaching are a new and useful feature of this edition. We strived to represent in our exercises all three phases of research in astronomy, i.e. collection of data (by observation, measurement or from literature), data reduction (by machines and computation) and data interpretation (models, theory). The exercises will help the students to acquire skill in these three activities and the concepts introduced in textbooks and in lectures become clear, tangible and real.

Many astronomical exercises are scattered in various journals (*American Journal of Physics, Mercury, Physics Teacher, Sky and Telescope et al.*). Among books on practical training in astronomy let us mention: "Astronomie — méthodes et calculs" by A. ACKER and C. JASCHEK (Masson 1981), "Selected Exercises in Galactic Astronomy" by I. ATANASIJEVIĆ (Reidel 1971), "Practical Astronomy with Your Calculator" by P. DUFFETT-SMITH (Cambridge University Press 1979 and 1981) which was translated into Russian as "Prakticheskaya Astronomija s Kalkuljatorom" (Mir, Moscow 1982), "Prakticheskye Raboty po Zvezdnoj Astronomii" by P. G. KULIKOVSKIJ *et al.* (Nauka, Moscow 1971), "Teacher's Guide for Contemporary Astronomy" by JAY M. PASACHOFF (Sounders College Publishing, New York 1981), "A Workbook for Astronomy" by J. WAXMAN (Cambridge University Press 1984), "Spetspraktikum po Astrofizike" by A. V. ZASOV *et al.* (Moskovskij univerzitet 1983), "Astronomische Übungsaufgaben" by O. ZIMMERMANN (Bibliographisches

Institut Mannheim 1966). A complete and up-to-date list of bibliographical references to astronomical exercises from all over the world is published half-yearly in "Astronomy and Astrophysics Abstracts" (Springer Verlag, Berlin), in which section 014 is devoted to "Teaching in Astronomy".

Minnaert's exercises have been reprinted by a large part without changes. One important aspect of theirs was in learning how to use libraries. They were taught at Utrecht University and References therefore refer to the University Library. The user of this edition will, however, have no difficulty in finding textbooks, monographs, journals, catalogues, ephemerides, atlases and other information sources published in recent years. Any modern University Library will help you. Another point should be mentioned with regard to Minnaert's exercises: today, every student has a pocket calculator which can be used as an alternative for a slide rule or logarithmic tables. Minnaert's exercises are marked by the same symbol as in the first edition, i.e. by a capital letter (A or B) with a number.

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JOSIP KLECZEK

TO THE INSTRUCTOR

Astronomy is a science of nature. It is based on observation, and it is to the results of the observations that theory and calculation are applied. Our practical work, therefore, will have to show the concrete reality of the celestial objects, studied during the lectures: as far as possible this practical work should run parallel with the theoretical courses.

Practical work in General Astronomy can be organized along very different lines. We shall mainly describe the course which has been developed at Utrecht during a period of some 25 years. It is intended for freshmen; future mathematicians, physicists and astronomers, who from the very start should be confronted with the sky before they are asked to look at the blackboard! They are expected to know some trigonometry, the elements of calculus and physics; but the astronomical problem will always be put central.

The students are formed into groups of about 25, working in pairs; each group on a fixed evening of the week.

By letting all the students work simultaneously, a rather close synchronization with the course on General Astronomy becomes possible. The introductory explanations can be given collectively; a comparison between the results allows an estimate of the accidental errors and introduces stimulating competition. On the other hand, care should be taken to leave sufficient time for free individual initiative; the paragraph numbers, put within parentheses and the literature references are especially intended for such purposes. After all, there is no obligation to finish each exercise within just one evening.

The principle of simultaneous work has the consequence that each instrument must be produced in quantity: one for each pair of students. Consequently, only simple instruments can be made available, such as will be described in the beginning of this volume.

Whenever the sky is clear, observations are made from a terrace in the open air. Directly afterwards the results are used as a basis for simple calculations. Observations through a medium telescope, placed inside a dome, are made in between the other parts of the programme; the students are called two by two, and have to interrupt their work only for a few minutes.

When cloudy, photographic records or other documents are studied, instruments tested, or practical calculations carried out. These are no scholastic exercises: the professional astronomer also devotes a great part of his time to such laboratory work.

Two programmes are prepared for each evening, one of each kind, and a choice is made one hour ahead. Each exercise in this book describes such a programme, mostly planned in such a manner, that it can be carried out in about 3 hours.

In general it will not be possible to carry through the whole programme of this book;

a choice should be made according to weather conditions, instruments available, predilection of the instructor, and number of hours available. The choice will also be different for those students who specialize in astronomy and for those primarily interested in mathematics or physics.

It would be desirable to have the students working in the library, surrounded by books and periodicals, consulting any sources they wish and getting the material first-hand from the original publications. In our experience this has proved possible as long as the number of students was small, but even then the material became partly spoiled. With greater numbers of students it was unavoidable that a great part of the reference material had to be reproduced by photocopy; these photographs were then protected by a thin cellophane sheet.

When starting this practical work in astronomy, we were inspired by the wonderful early work of H. T. Stetson, R. K. Marshall, O. L. Dustheimer and other American astronomers, from which the basic ideas for some of our more elementary exercises are borrowed. These remain necessary as long as astronomy is not generally taught in secondary schools. A good instructor will nearly always be able to make them 'scientific'; the literature references may be of use for this purpose. On the other hand, European university education does not correspond to the American college and requires a somewhat more thorough treatment for more specialized students. For those less elementary exercises no examples seemed available and we had to find our own style. Avoiding therefore a course of only theoretical little problems, we have inserted direct observations, the study of astronomical photographs, and the use of simple instruments, as often as allowed by the climate and the available instrumental means. Our practical exercises have developed all the time in the course of the years, according to experience gathered in working with the students and to ideas suggested by the instructors. A few instruments, especially constructed for our practical course, were successively improved in constant consultation with our workshop. Descriptions will be found on pp. XV–XXIII.

Let me express the wish that practical work in elementary astronomy will soon be generally introduced in university teaching and that our experiences, here described, will prove of some use for this purpose. We have found it most enjoyable to build up such a course and we are sure that others will find the same satisfaction in this creative work.

BOOKS ON PRACTICAL WORK IN ASTRONOMY
(Mainly for the elementary exercises).

DAGAJEV, M. M.: 1963, *Laboratorny Praktikum po Kursu Obshtshey Astronomii*, Moscow.
Deutsches Pädagogisches Zentralinstitut: 1962, *Praktische Schüler-beobachtungen für den Astronomie-unterricht*, Berlin.
JASCHEK, C.: 1968, *Exercises in General Astrophysics*, in press (for more advanced students).
SHAW, R. W. and BOOTHROYD, S. L.: 1958, *Manual of Astronomy*, Brown Co. Publishers, Dubuque.

TO THE STUDENT

A student, following a course in astronomy, expects that now at last he will see with his own eyes the wonders suggested by the scintillating stars in the depth of the night sky. This expectation will be fulfilled, though some work and effort will be necessary. To observe through a telescope requires *exercise*. The study of photographs is a study of *symbols*, of which the real meaning has to be discovered by reflection. During the work one should try to realize how immense, how harmonious is the structure of the Universe which we are trying to explore. You may be sure that the professional astronomer has the same feeling of wonder and awe. Seldom will he speak about this, but it inspires him all the time in his work.

For a series of selected topics our practical work will demonstrate the methods which are used in the investigation of the Universe, not getting down to technicalities, but concentrating on the principles. It should convey to the student some idea of the work of the astronomer in his professional practice. It is not primarily intended to teach technical skill, but the student should learn by practice the style of scientific investigation and the methodology of research work.

We shall work with very simple, home-made instruments. This is necessary, since many of them are needed; but it has also the advantage that the essentials of the method become more apparent. However, the student should understand that he must always endeavour *to reach the highest precision attainable* with a given instrument even when this instrument is primitive. The following implements are constantly required:

compasses, big protractor, slide rule;

a note-book without lines; a copybook; sheets of rectangular co-ordinate paper (by preference red).

The students work two by two. Usually one of the partners observes, while the other records the figures; after each series the roles are reversed. These records should be made *orderly* and *methodically* in the note-book, and should in no case be corrected later. Then each partner writes a short report in his copybook, containing all the observations mainly *in tabular form.* (Many examples will be given; you are free to arrange your results in other ways.) To make a good scientific report requires special skill and experience, which should be acquired early. Bear in mind that after three months your report should still be readable and understandable!

Not all students are equally quick. The tasks, therefore, are arranged in such a way, that the first paragraphs are the most essential ones, and that following paragraphs, indicated by numbers between parentheses, can be chosen as interesting complements for those who have finished the main programme. Any personal initiative will be encouraged!

Graphs and calculations are made by each of the partners independently, the results being compared after each step, which gives a good check: professional computers often do the same. It is preferable to have the reports made directly after the observations, while these operations are still fresh in the memory.

Drawings of observed objects should be made by each partner on a sheet of the note-book and then glued into the copybook (glue at the topcorners only!). No artistic ability is required to make such a drawing; it helps you to realize what you are seeing and to express your conceptions by simple sketches.

This is not school, it is scientific research, albeit at an elementary level. We work in order to *understand* things. The assistants will not rate your merits, they will just try to explain and to guide. You can use books and lecture-notes, you can consult the observatory library, you are invited to help each other and to discuss questions that might not be clear, but conversation, not related to our work, would be disturbing.

In our Instructions:
Observations on the *sky* and operations in the *laboratory* are distinguished by the characters *S* and *L* after the paragraph numbers. Numbers between parentheses refer to paragraphs, not essential for the main problem of the exercise.

General References

ALLEN, C. W.: 1963, *Astrophysical Quantities*, London.
BRANDT, J. C. and HODGE, P. W.: 1964, *Solar System Astrophysics*. McGraw-Hill, New York.
CHAUVENET, W.: *A Manual of Spherical and Practical Astronomy* (several editions; reprinted in the Dover Publications, 1960).
DANJON, A.: 1952–53, *Astronomie générale*, Paris.
DANJON, A. et COUDER, A.: 1935, *Lunettes et télescopes*, Paris.
KUIPER, G. P. and MIDDLEHURST, B.: 1953–1963, *The Solar System* (Vol. II–V), Chicago.
KUIPER, G. P. and MIDDLEHURST, B. M.: 1960, *Stars and Stellar Systems* (Vol. I–VIII).
UNSÖLD, A.: 1955, *Physik der Sternatmosphären*, Berlin.

OBSERVATIONS FOR AMATEURS

ROTH, G. D.: 1960, *Handbuch für Sternfreunde*, Berlin.
SIDGWICK, J. B.: 1956, *Amateur Astronomer's Handbook*, London.
A number of copies to be available of:
Norton's Star Atlas (Gall and Inglis, London, many editions).
The Astronomical Ephemeris; in many cases copies of former years may be used.

TECHNICAL NOTES CONCERNING THE PRACTICAL WORK IN ASTRONOMY

For our practical work we need:

(a) an observing terrace;
(b) an astronomical telescope, mounted in a dome;
(c) a 'laboratory', where indoor-work is carried out.

It is of great advantage if these three units are in *direct* proximity to each other.

(a) It is not easy to find a convenient *terrace* for students' observations. A free sky is of course desirable, a free view towards the South is especially important. On the other hand, it is a considerable advantage if the observing terrace is surrounded by low walls and by trees (at some distance), as protection against the wind and for screening off city-lights.

On the terrace we have a series of small pillars, one for each pair of students (Figure 1). They each have their serial number; on each of them a small experimental telescope with the corresponding number can be placed in a fixed position. The pillars are hollow and open from behind. Inside there are weatherproof plug points for alternating electric current 24 V.

Light metal chairs should be provided for exercises in which drawings have to be made.

Recently a series of small mountings have been constructed, to which a camera for celestial photography may be clamped; each may be rotated by a synchronous electromotor with the normal diurnal speed. We have no experience as yet with this installation.

(b) We use a *refractor* with an objective of 25 cm and a focal length of 3.50 m. It has a fixed connection to the gears; and a quartz-clock, giving sidereal time, is built in, so that declination and right ascension may be read directly from dials. The technique of working with graduated circles and of transforming hour angle into right ascension is learned by the students when they work with their small experimental telescopes; consequently it may be dispensed with when objects are demonstrated with a real telescope.

(c) The *laboratory* should be equipped with long tables, where atlases etc. can be laid out. Books and tables should be available, not only the elementary textbooks, but also some of the professional reference works. If possible some series of the important astronomical journals should be included.

The tables should have electrical contact-boxes for 24 V for the use of photometers or other instruments and 220 V for local illumination. Not too far from the terrace there should be two astronomical clocks, one giving Universal Time, the other Local Sidereal Time.

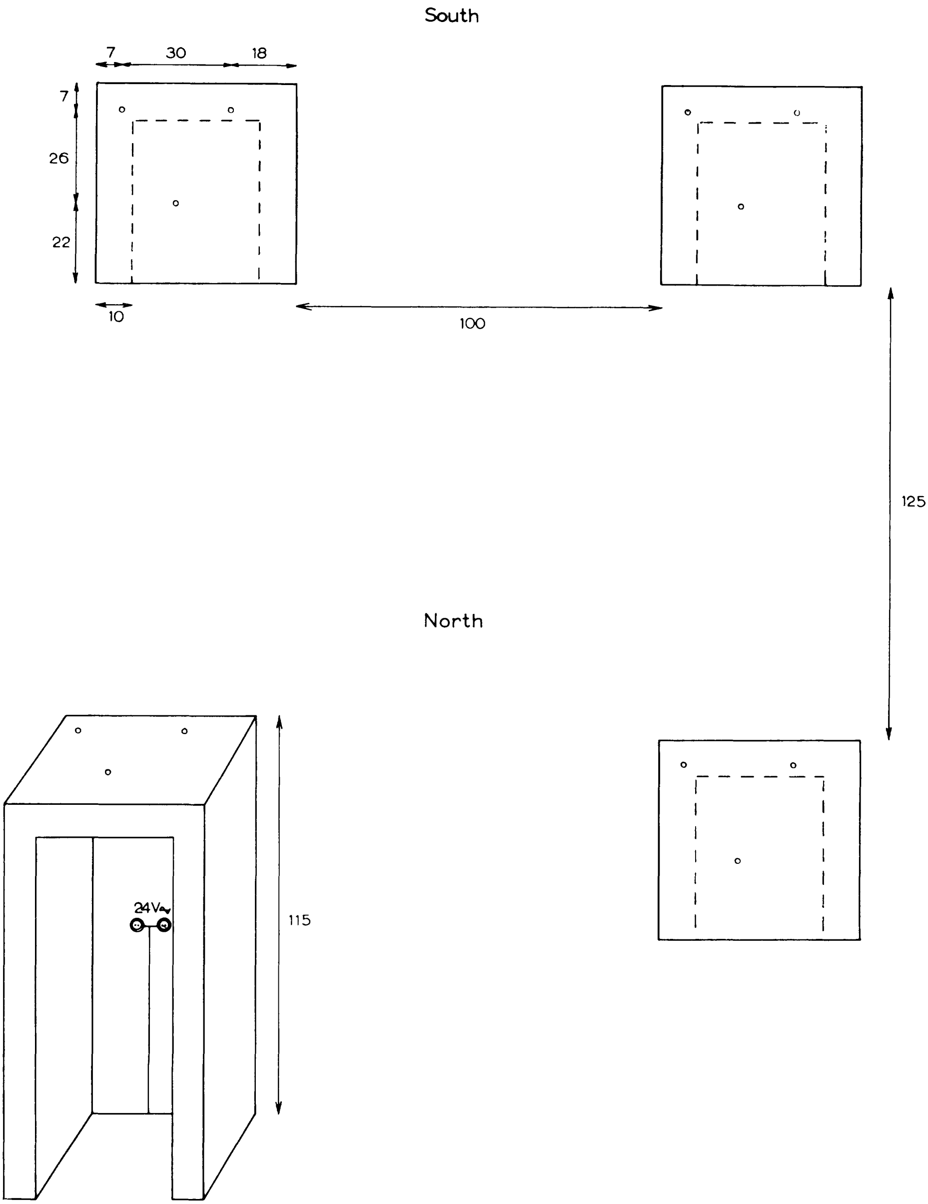


Fig. 1. Arrangement of the observation pillars on the terrace. All measures in centimetres.

Some Students' Instruments, constructed in the Observatory workshop

1. *Experimental telescope* (Figures 2 and 3). The objective is a small achromatic lens, diameter 40 mm, $f = 500$ mm. The instrument is equatorially mounted. The polar axis is adjusted in altitude by one of the screws of the tripod. The adjustment in azimuth is obtained by means of a joint between the main vertical axis and the polar axis; this is clamped in such a way that the adjustment, once attained cannot be disturbed by the students. There are two circles, graduated with white lines on a black ground; the declination is graduated in whole degrees, the hour-angle in divisions of 6^m.

The ocular is of the Ramsden type, $f = 25$ mm. For some observations a stronger eye-piece is useful ($f = 9$ mm).

In the focal plane there is a fixed diaphragm of 15 mm and a reticule having two mutually perpendicular lines, oriented along the parallel and along the hour-circle (Crosswires were found to be too vulnerable). A simple dew-cap is found very useful.

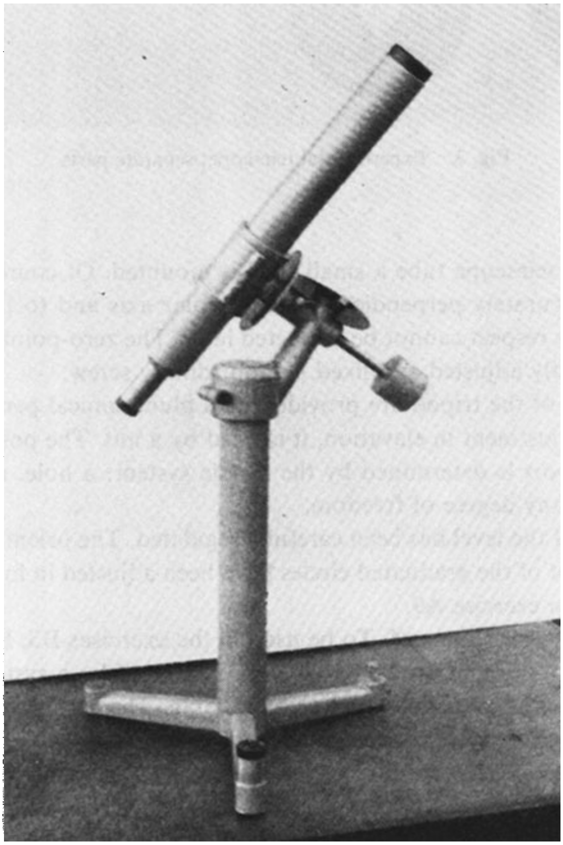


Fig. 2. Experimental telescope. Focal distance 50 cm. Height of vertical column 45 cm.

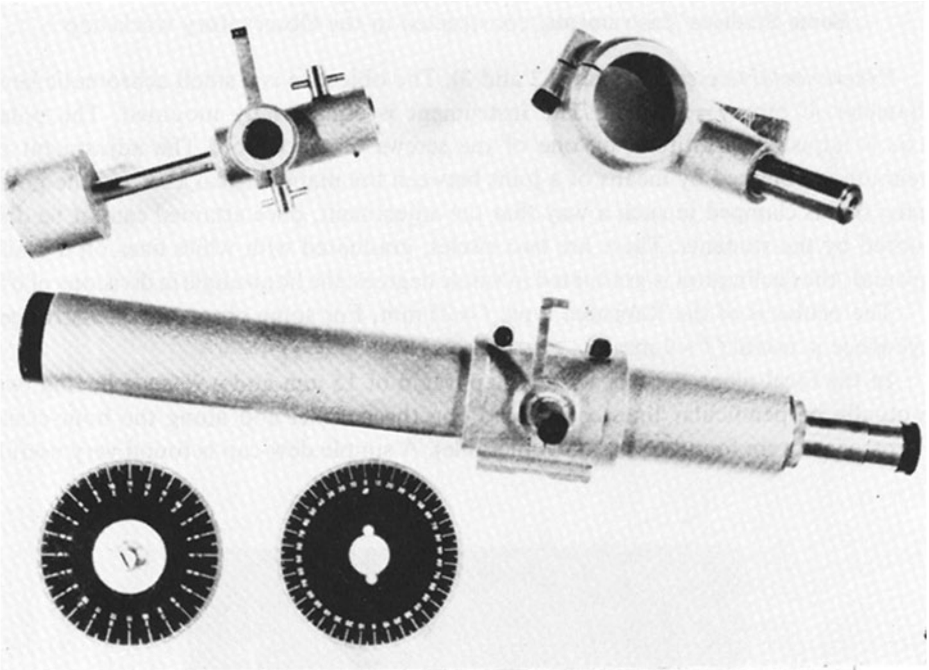


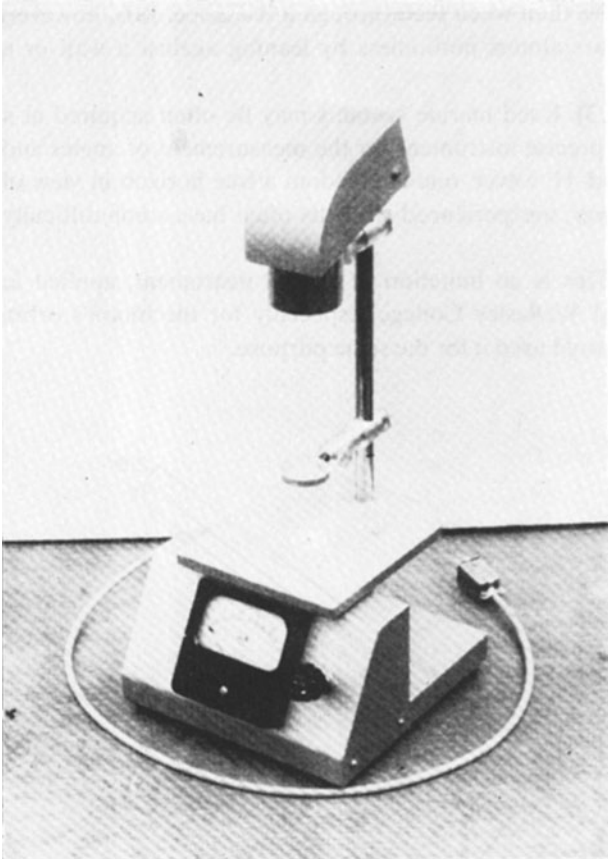
Fig. 3. Experimental telescope; separate parts.

On top of the telescope tube a small level is mounted. Of course the declination axis should be accurately perpendicular to the polar axis and to the telescope axis, since errors in this respect cannot be corrected later. The zero-point of the graduated circles may be easily adjusted and fixed by an ordinary screw.

The three legs of the tripod are provided with blunt conical pens; one of them is a screw for the adjustment in elevation, it is fixed by a nut. The position of the three legs on their support is determined by the classic system: a hole, a groove, a plane – which removes any degree of freedom.

The position of the level has been carefully regulated. The orientation of the polar axis, the zero point of the graduated circles have been adjusted in first approximation and are checked in exercise A9.

2. *Microphotometer* (Figure 4. To be used in the exercises B3, B5, B18). A small incandescent lamp, burning on 12 or 24 V~, is imaged by a system of 3 ordinary spectacle glasses on a small hole in the object table. The rays passing through this hole illuminate a photovoltaic cell, the current of which is recorded by a 100 micro-ampere meter, mounted on the foot of the instrument. By slight shifts of the lowest lens, the maximum concentration of the rays on the aperture may be obtained. In that case the microampere-meter reaches nearly its full deflection: the sensitivity of the instrument has been so adjusted.



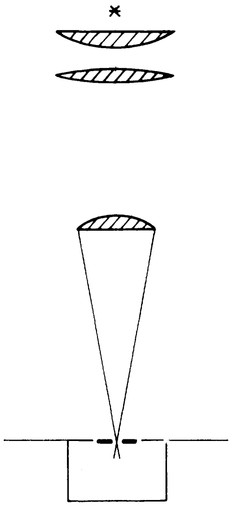


Fig. 4. Students' microphotometer.

[By using the modern solar cells it becomes possible to reduce considerably the brightness of the incandescent lamp, which is an appreciable advantage.

Another possibility is the use of cadmiumsulphide photo-resistors. The source of the electric current has then to feed the lamp as well as the photo-resistor.]

In order to avoid fluctuations of the tension, all students have to connect or to disconnect their photometers at the same time. It will be of course an advantage if, for each pair, the current is first rectified, then stabilized (stabilization to 1% will do).

The photographic plate to be investigated should be kept in closest contact with the object-table, the gelatine side should therefore be the downward side. In order to avoid scratches, a piece of smooth coordinate paper is put on the object table, leaving only the centre free. Edges of the metal plate should be rounded off and kept smooth.

3. A few pairs of *binoculars* are used as a transition between observations by eye and observations through the experimental telescope. Because of the wide field many

objects are even more impressive than when seen through a telescope. It is, however, necessary to keep the binoculars almost motionless by leaning against a wall or a door-post.

4. *Sextant* (Cf. exercise A13). Used marine sextants may be often acquired at a moderate price. It is our most precise instrument for the measurement of angles and it does not require a fixed stand. However, one has seldom a free horizon in view of altitude measurements. Moreover, inexperienced students often have some difficulty in getting the right field of view.

5. *Cross-staff* (Figure 5). This is an imitation of an old instrument, applied in elementary practical courses at Wellesley College, especially for the moon's orbit; later Marshall and Shaw-Boothroyd used it for the same purpose.

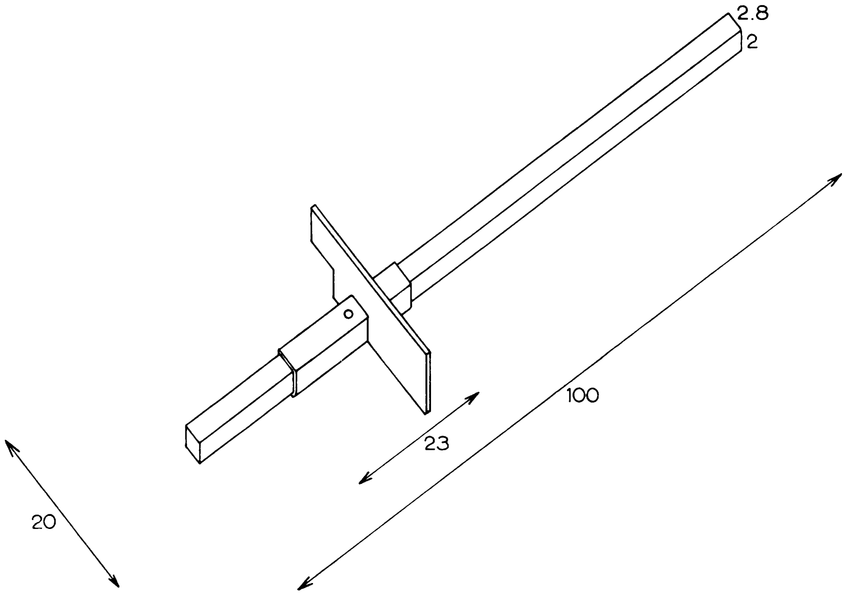


Fig. 5.

On the lower side of the staff two scales are found, corresponding respectively to the long and to the short side of the cross. Once the right adjustment is obtained, a screw is gently tightened in order to fix the position and the reading is made.

In establishing the scale, the distance between the eye and the extremity of the bar has been taken into account. The scale divisions correspond to steps of 1°, tenths are easily estimated. The scale is protected by a glass cover.

6. *Altimeter* (Figure 6. To be used in exercises A7, A14). In a triangular block of concrete a vertical iron tube A has been inserted, 63 cm high, 4.3 cm wide. A second, slightly narrower tube B (3.3 cm) inside the first one slides up and down and may

be fixed by a hand-screw. Tube *B* has near its end a screw, serving as an axis for the wooden measuring tablet (Figure 6).

This tablet has the size of 48 × 24 cm; it carries two dioptres *M*, *N*, a light pendulum suspended in *A*, and a scale *BD*, graduated in cm and mm. The distance between *A* and *BD* is taken equal to 20 cm, in order to simplify the computations. We direct the tablet so that the object is seen in the dioptres, we clamp the winged nut and read the intersection *C* of the vertical thread with the scale. – When not in use, the pendulum weight is inserted between two springs.

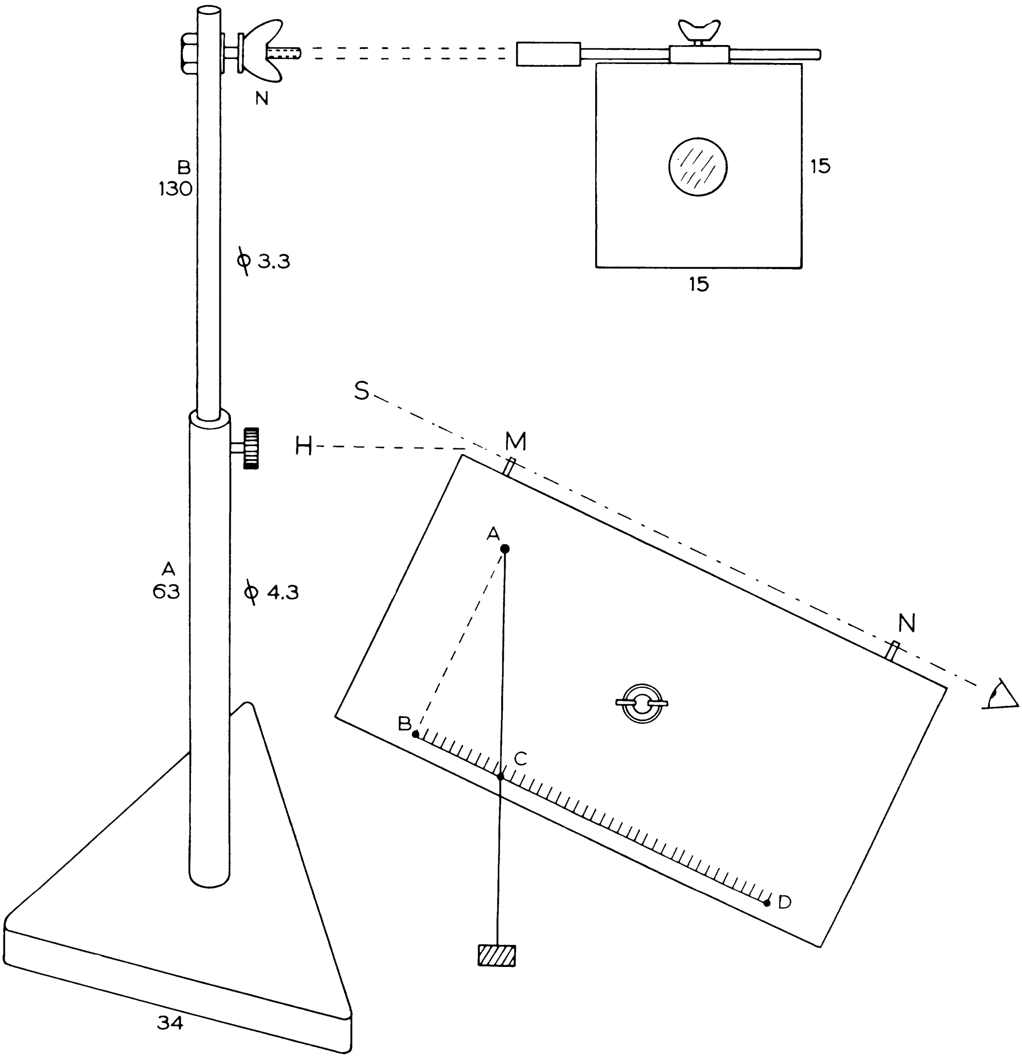


Fig. 6.

To the same axis at the upper end of tube B may be screwed a simple adjustable lensholder for exercise B1.

For exercise B2 the inner tube is removed and replaced by an articulated head, carrying our simple pyrheliometer.

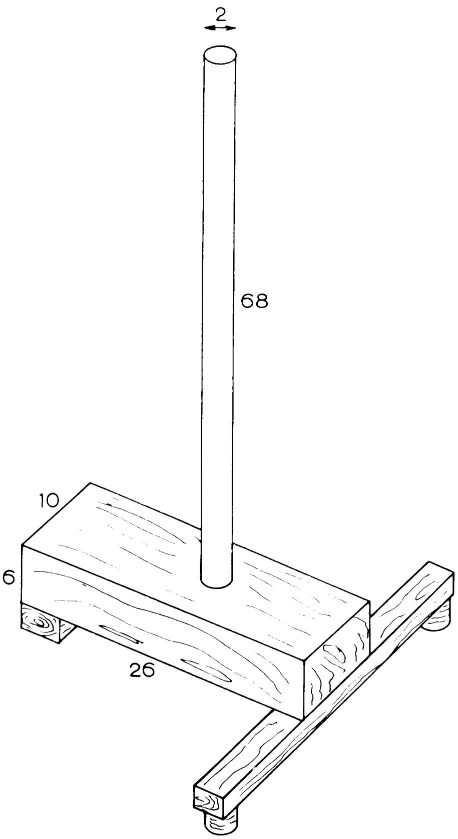


Fig. 7.

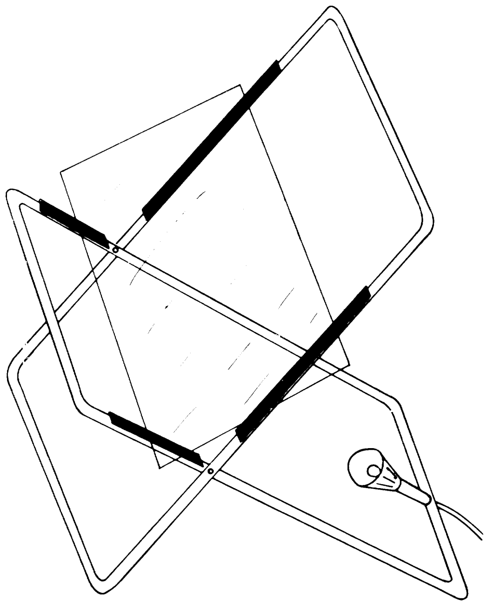


Fig. 8.

7. *Light wooden stands*, carrying a vertical iron tube, are used in order to clamp screens or diaphragms (Figure 7).

8. A *pulpit* (Figure 8), made of aluminium strips, is covered with plastic tube along part of the strips. On this pulpit a plate of milk glass may be put under some inclination, serving as a bright background for spectrograms or other photographic plates. The milkglass is illuminated from below by an incandescent lamp L, carried by a movable arm.

9. *Lamp*. For illumination of note-books or instruments with graduated circles and cross-wires, special lamps have been constructed (Figure 9). – They have a switch

S and can be damped with a resistor *R*. The light is emitted sideways from a hole *H*; one can choose between red or white. By means of a simple stand the lamp may be put in an inclined position, giving a faint light on the Star Atlas. On both ends the cylinder is protected by rubber rings.

Before electric current (24 V ~) was available, we used flashlights, but then a regular and annoying check on the batteries was necessary. Dimmed light was obtained by using a lamp for which the battery gave too small a tension, or by inserting sheets of paper.

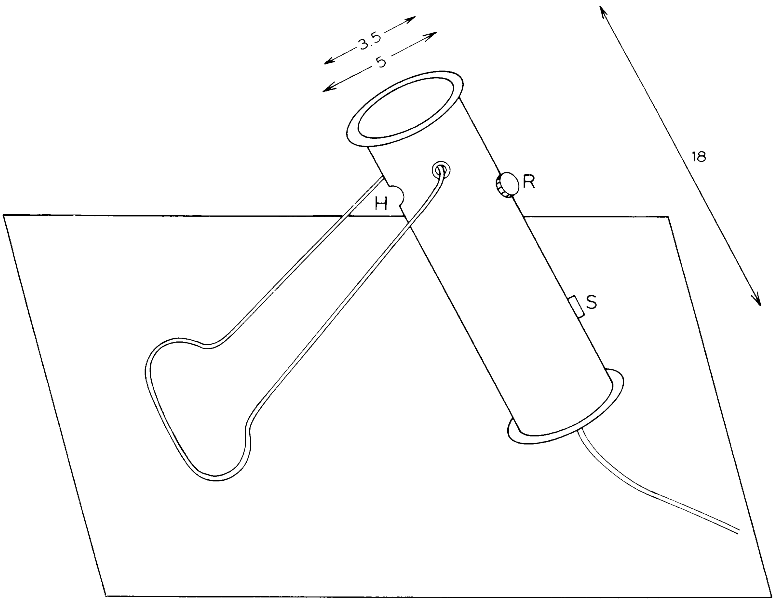


Fig. 9.

10. *Template* for plotting star positions (Cf. exercise A1). A strip of copper, 4 cm × 1 cm, thick 0.12 mm. Holes are pierced with diameters of 2.2; 1.5; 1.2; 0.9; 0.5 mm.

11. *Microscale* for measuring the diameter of photographic star images. This is a photographic reproduction on glass of Figure 10, the enlargement being so chosen that the scale becomes a millimetre division.

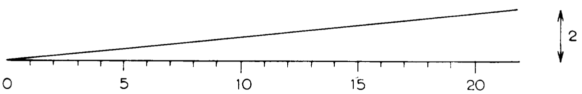


Fig. 10.

12. *Magnifier*. A plane-convex lens, mounted in a simple brass ring with a small handle. Students should be instructed to turn the convex side towards the eye and always to keep the eye quite close to the lens.