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FARWELL-STIFLER OPTICAL BENCH

As Used in Columbia University in the College Physics Laboratory and in the Optometry Courses

This ingenious optical bench, designed by Messrs. Farwell and Stifler of the Physics Department in Columbia University, is the practical outcome of a wide experience in the teaching of optics. It possesses all the merits both of simplicity and of efficiency which are so desirable in an apparatus of this kind. A brief description of this bench was published in the *American Journal of Science* for November, 1913.

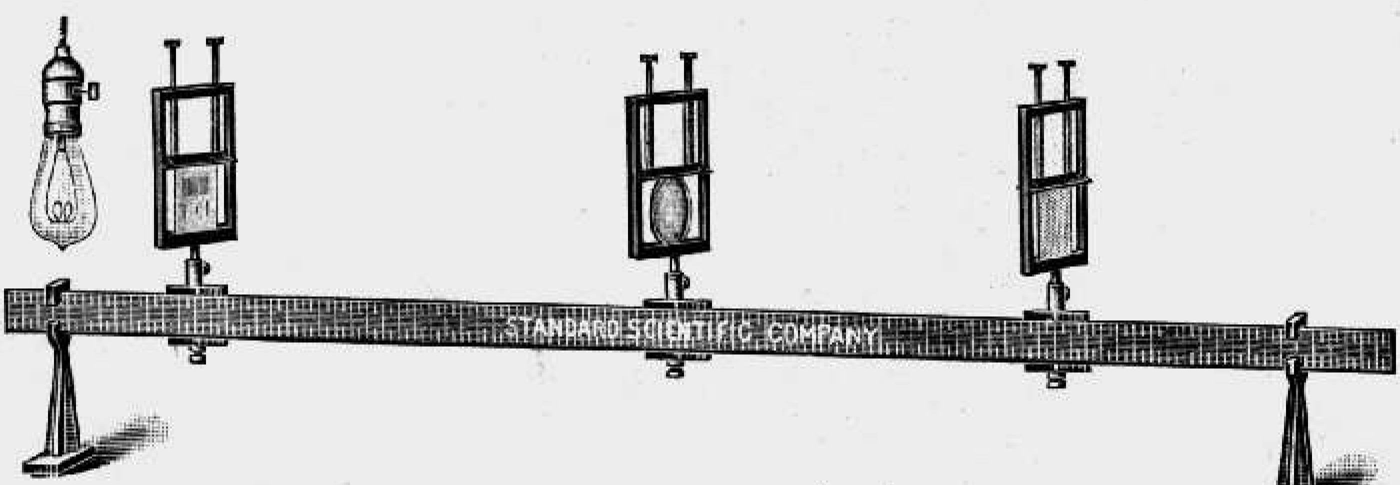
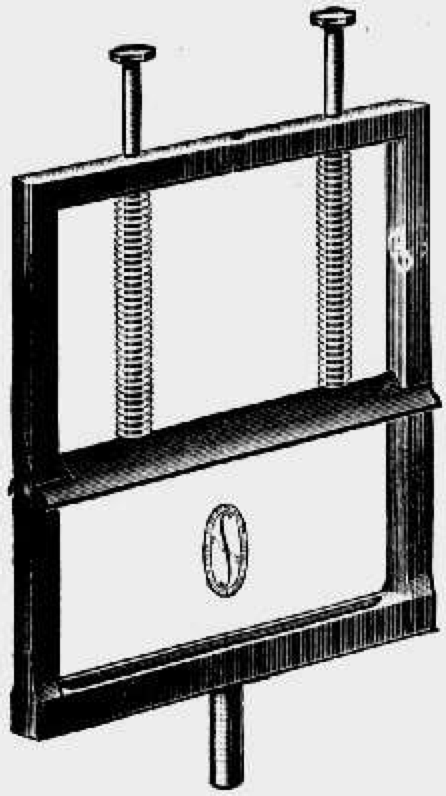


FIG. I.
FOCAL LENGTH OF LENS BY CONJUGATE FOCI.

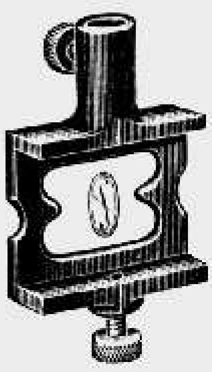
The optical bench itself consists of a bar (a two-meter or one-meter stick) supported by three (or two) iron legs (**J1320**) which can be fastened at convenient positions. Though the bench when made up with a two-meter stick and three legs is much to be preferred to the smaller form, all the figures in this bulletin are made from the one-meter bench in order to show the details of the smaller pieces. The bar carries

Directions for Laboratory Exercises in Optics with Optical Bench. Price 10c. each, $1.00 per Doz.

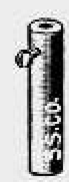
J1320



J1324



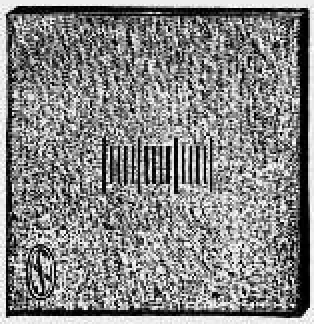
J1322



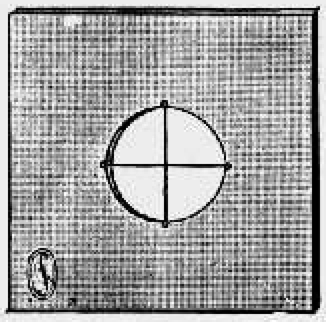
J1326

a number of sliding clamps (**J1322**), each of which will receive a "universal" holder (**J1324**) or a pin-holder (**J1326**). The diagram (Fig. 1) shows the ease and accuracy with which the position of the clamp on the bar can be read. The "universal" holder will serve equally well for mirrors, lenses or screens, a fact which will be much appreciated by those who desire simplicity of apparatus. For the more simple experiments three clamps, three "universal" holders, two pin-holders are sufficient; and we have listed this equipment, with bar and legs, as a set. To perform the more complicated experiments, such as those involving combinations of lenses or mirrors, it is necessary only to increase the number of clamps and "universal" holders.

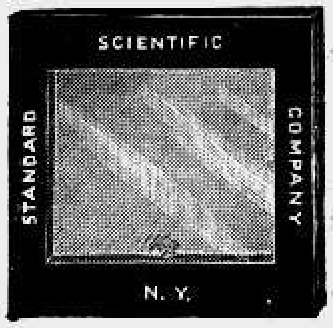
While the above pieces constitute the essential parts of the apparatus, experience has shown that the following accessories often add to the usefulness and convenience of the equipment:



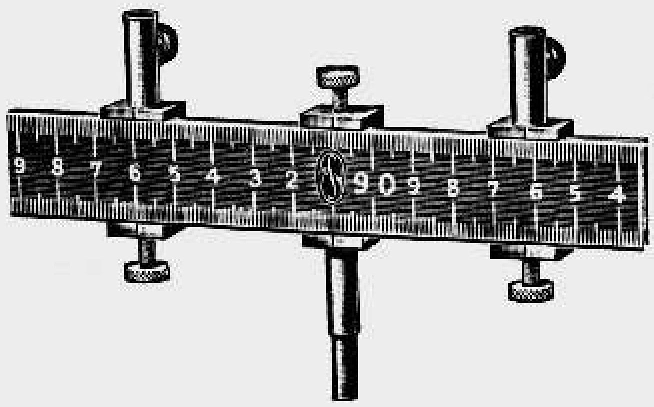
J1328b



J1330b



J1145



J1336a

J1336b

Ground Glass Screens (**J1328a and b**) with and without short millimeter scale ruled in center;

Opaque Screens (**J1330a and b**) with circular aperture, with and without cross-wires;

Gelatine Replica Diffraction Grating (**J1145**);

Transverse half meter stick (**J1332**) with central slit;

Nodal Slide Equipment (**J1336**) for determination of Equivalent Focal Length and Nodal Points of Combination of Lenses.

USES

This apparatus has been designed for efficient service, and a short description of its use in a number of experiments will illustrate its advantages in this respect. We might add that an actual demonstration is even more convincing.

I. Plane Mirror.—*Location of virtual image. Parallax Method.* A pin with white head (object) is placed in the pin-holder (**J1326**) at any convenient distance in front of the plane mirror which is placed in the "universal" holder at right angles to the bar. A tall pin with black head is placed in a pin-holder behind the mirror. The adjustment may be made by moving either pin backwards or forwards until the top of the black pin, as seen over the top of the mirror, coincides with the image of the white pin as seen in the mirror from any position. This parallax method is very simple and capable with a little practice of giving very accurate results. Of course, indirectly, this experiment is equivalent to a proof of the law of reflection.

II. Spherical Mirrors, Concave or Convex.—*Location of Center of Curvature and Determination of Focal Length by Conjugate Foci, using either real or virtual image.* A typical illustration of the range and adaptability of this apparatus may be shown by the variety of ways of performing any one of the standard experiments with spherical mirrors. For example, the center of curvature of a concave mirror is often found by determining the position at which object and image coincide. With our new equipment this point can be found immediately by using the opaque screen (**J1330b**) well illuminated from behind, and adjusting the position of the mirror until the image of the cross-wires is sharply focussed on the screen beside the aperture. If now, without altering the position of the clamp, a pin in a pin-holder is substituted for the screen and "universal" holder, a slight *rotation of the mirror about its vertical axis* will bring the real image of the pin into coincidence with the pin itself. This shows the exact equivalence of parallax and screen methods. Incidentally, this illustrates two points of superiority of this apparatus over the ordinary elementary optical bench, viz.: (1) the instant and exact substitution of pin for screen, and (2) the possibility of rotating the optical axis of the system into any desired vertical plane.

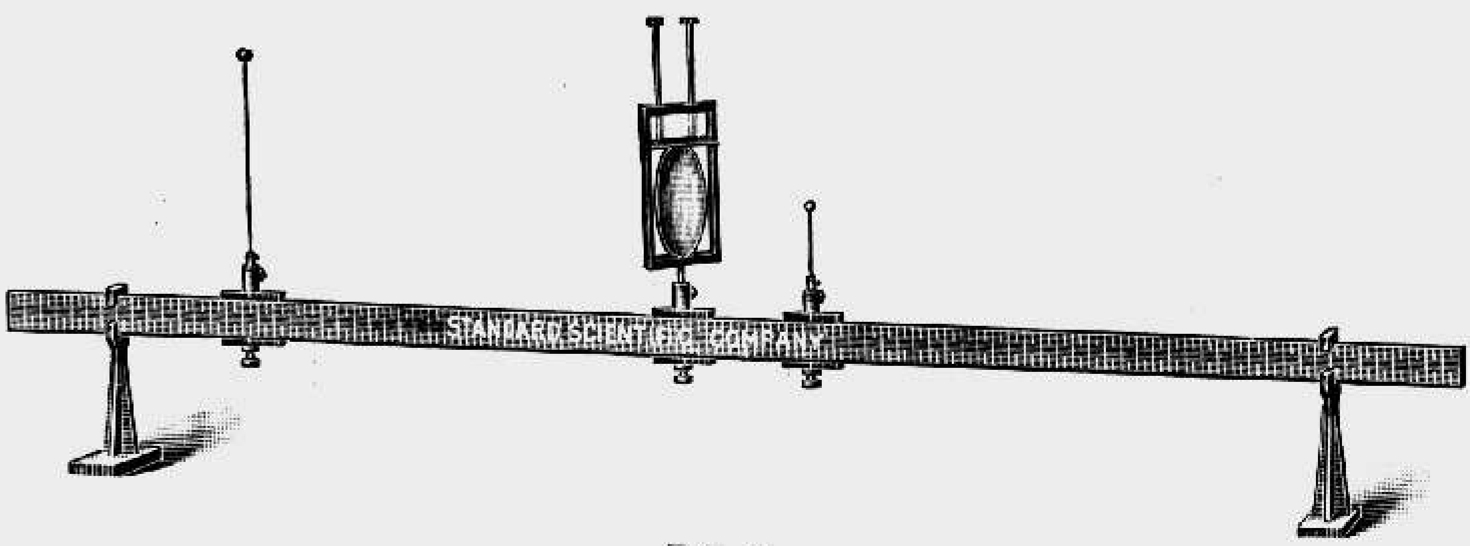


FIG. 2.

FOCAL LENGTH OF SPHERICAL MIRROR—EMPLOYMENT OF VIRTUAL IMAGE.

In a similar manner the position of the conjugate foci for real images may be determined by some one method and instantly checked by two or three other methods. The position of virtual images, of course, can be determined only by the parallax (or pin) method. With most elementary optical benches, it is difficult, if not impossible, to determine the position of a virtual image; this is due primarily to the impossibility of placing the mirror accurately at right angles to the line joining object-pin and image-pin. Since our "universal" holder permits a *lateral adjustment* of the mirror in addition to the *rotation about a vertical axis* already noted, it is easy to make the principal axis of the mirror pass through the two pins (Fig. 2). Hence, *the focal length can be determined by means of virtual images with an accuracy comparable with that obtained by real images;* and the virtual images afford an excellent way of emphasizing the *proper use of signs* in the image formula:

$$\frac{1}{\text{Object-distance}} + \frac{1}{\text{Image-distance}} = \frac{1}{\text{Focal length}}.$$

By using dividers and scale, the size of a real image as found on either screen **J1328** or **J1330** may be readily measured. If screen **J1328b** is used for the object, the magnification is readily determined. This gives a check on the ratio of image-distance to object-distance. These measurements can be made on any of the commercial benches, but for rapidity, accuracy and interchangeability, our bench is in a class by itself.

III. Spherical Lenses, Converging and Diverging. *Determination of Focal Length by Conjugate Foci* (Fig. 1). The advantages of this apparatus already enumerated are shown with even greater emphasis in the experiments with lenses. The methods are of course similar to those used with mirrors, and further details are perhaps unnecessary. It might be mentioned that *the whole equipment is so light and yet sufficiently rigid and secure* that it may easily be carried near a window in order to find in the sunlight the focal length of a lens by setting a screen at the burning point.

The problem of determining experimentally *the focal length of a diverging lens*, often left to the imagination of the student, becomes with this equipment as simple as for a converging lens.

IV. Combinations of Lenses and Mirrors. Such simple combinations of lenses as *models of the astronomical and terrestrial telescopes and compound microscope* are of great interest to the average student of elementary optics. The objection to setting up such models with most benches lies in the difficulty of accurately *centering* the lenses. This is particularly true in case the exigencies of laboratory equipment require the use of lenses of different diameters. Here again our bench meets the practical need, for the clamp and "universal" holder give *vertical adjustment* of ample range. On few, if any, of the other moderate-priced optical benches can a *model of the reflecting telescope* be set up.

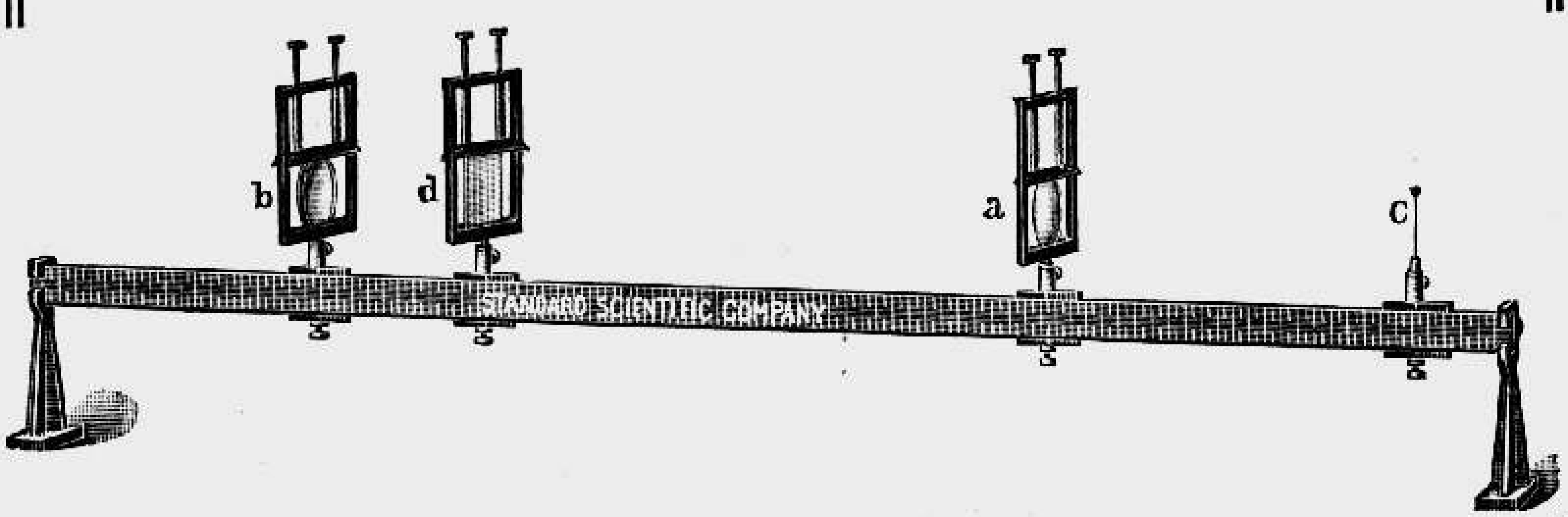


FIG. 3.
ARRANGEMENT FOR COMPOUND MICROSCOPE.

As an illustration of the formation of images in a compound optical instrument, *the setting up of a microscope* will be described (Fig. 3). It is supposed that the stuentd has completed the exercises with simple lenses, and is thus familiar with the image process in general.

The object *c*—pin or screen—is placed in the holder near one end of the bar. By means of the object-glass *a* an enlarged inverted real image is formed on ground glass screen *d*. The lens *b* corresponding to the eye-piece is then set in such position as to form a virtual image (enlarged) of the granular surface on the screen. Thus far, the student has merely repeated two of his earlier exercises. If now he removes the screen *d*, he finds on looking through the system that his microscope is complete.

(As is shown in Fig. 3, this arrangement requires one more sliding clamp, **J1322**, than is included in either of the regular sets, **J1300** and **J1310**).

V. Wave-length of Light by Diffraction Grating. This experiment, if attempted at all in elementary courses, usually requires a spectrometer or a rather clumsy arrangement of more or less special appliances. With this bench, on the other hand, the determination of the wave-length of, say, sodium light, requires only the addition of a half-meter stick with a central transverse slit (**J1332**). Any grating and light-source suitable for such an experiment may be used. For convenience we have listed a Gelatine Replica Diffraction Grating, (**J1145**), which gives good results. A reference to the cut (Fig. 4) will make plain the actual arrangement of the apparatus. The half-meter stick is supported at right angles to the bench by means of two of the sliding clamps (**J1322**), held together by a pin-holder (**J1326**), from which the set-screw has been removed. The principle of the method consists in measuring

FIG. 4.
WAVE-LENGTH OF LIGHT BY DIFFRACTION GRATING.

on the half-meter stick the distances (p) from the slit to the various orders of spectrum-image, whence, knowing also the distance (d) of the slit from the grating and the value (a) of the grating space, we can determine the wave-length (λ) by the following formula:

$$\frac{n\lambda}{a}=\frac{p}{\sqrt{d^2+p^2}},$$

wherein n is the "order" of the spectrum-image. The images can be conveniently located by using paper-slides on the half-meter stick. The theory of the method can be found in any standard text-book of physics.

VI. Special Uses and More Advanced Applications. The experience of the designers of this apparatus is that it is capable of giving most satisfactory results in testing complicated optical systems. As an example of this, we may cite its use in the determination of the equivalent focal length and the ***positions of the nodal points*** of a combination of two or more lenses separated by several centimeters; thus illustrating one of the common problems in testing lens-systems. The theory of this

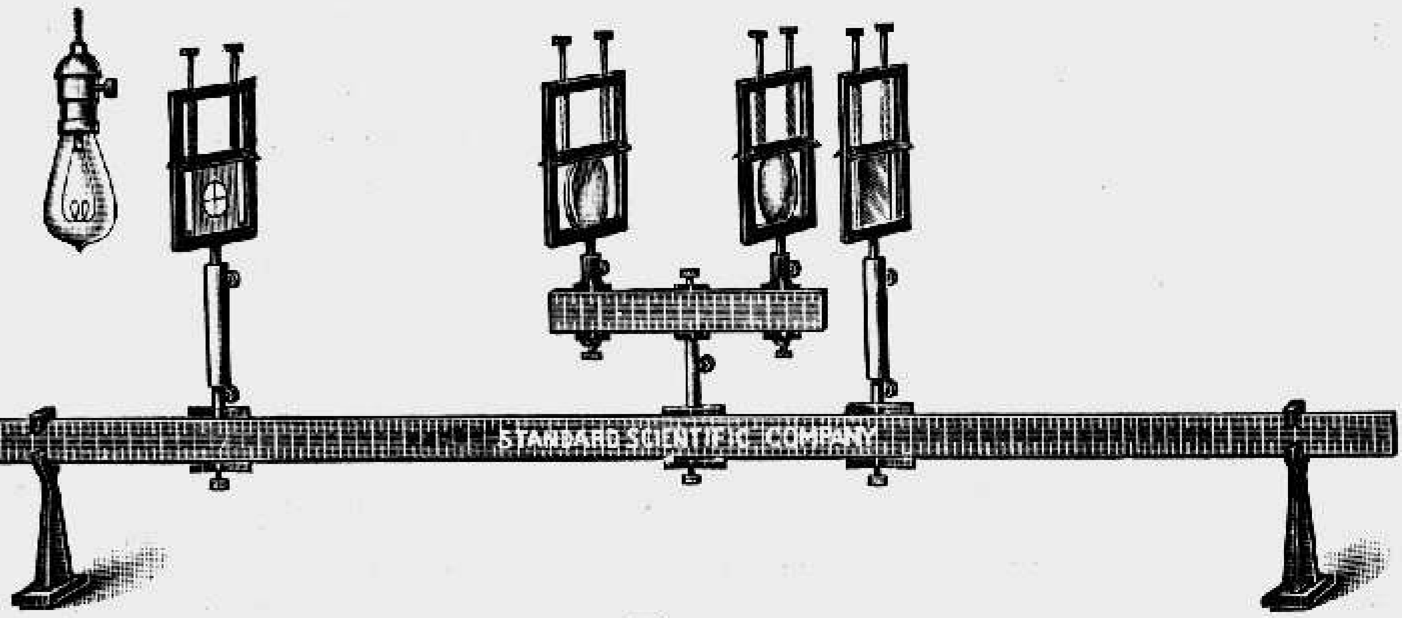


FIG. 5.
EQUIVALENT FOCAL LENGTH OF LENS COMBINATIONS.

method may be found in such books as Clay's *Treatise on Practical Light.* The diagram (Fig. 5) shows the special apparatus which takes the place of the elaborate "Nodal Slide" described by Clay. While a fairly satisfactory substitute for the "Nodal Slide" proper can be built up from our regular equipment, in practice it has been found that the special narrow clamps shown in the cut (**J1336a**) are advantageous here, though their general use is not recommended. Although, as is evident from the figure, this apparatus is not intended for commercial testing of such systems as photographic lenses, for emphasizing the principles involved in such tests the arrangement has evident advantages.

NOTE ON PROPER SELECTION OF OPTICAL EQUIPMENT

It may not be amiss to call attention to the fact that one of the main requisites for success in optical experiments of this nature is the choice of lenses and mirrors of suitable focal length and dimensions. For satisfactory results the focal length of spherical mirrors, both concave and convex, should be at least 15 cm. This focal length permits the use of a sufficiently large aperture (7 or 8 cm.) to give a brilliant image with very little distortion—a great aid to accuracy. In general, lenses of less than 15 cm. focal length should be avoided: for many experiments lenses of 25 or 35 cm. focal length are useful, since with these the images are less distorted. For most purposes lenses approximately 5 cm. in diameter are recommended. Since the minimum distance between an object and its real image formed by a lens is four times the focal length of the lens, it is obvious that with lenses of focal length 25 cm. or more, it is not possible to use the shorter (one-meter) bar. ***For general work the longer bar is very strongly advised.***

The purpose of this bulletin is to suggest but a few of the many possibilities of this ingenious apparatus in the teaching of optics. Many other applications will naturally occur to any enthusiastic instructor.

PRICE LIST

J1300	**Farwell-Stifler Optical Bench,** including two-meter bar with brass ends, 3 bench supports, 3 sliding clamps, 3 universal holders, 2 pin holders and set of pins, complete	6.50
J1305	**Farwell-Stifler Optical Bench,** similar to **J1300,** but including the Nodal Slide Equipment **J1336** complete	8.00
J1310	**Farwell-Stifler Optical Bench,** with one-meter bar, with brass ends, and 2 bench supports, but otherwise same as **J1300,** and set of pins, complete	5.30
J1315	**Farwell-Stifler Optical Bench,** similar to **J1310,** but including Nodal Slide Equipment **J1336** complete	6.80
J75a	**Meter Stick,** two meters long, brass ends	1.35
J75	**Meter Stick,** one meter long, brass ends	.30
J1320	**Farwell-Stifler Bench Support,** for meter stick, with clamping screw (3 required for two-meter bench, or 2 for one-meter bench)........Each	.50
J1322	**Farwell-Stifler Sliding Clamp,** with set-screw and index, for supporting Universal Holder **J1324,** Pin Holder **J1326,** etc. Designed to fit meter stick (3 required)........Each	.50
J1324	**Farwell-Stifler Universal Holder,** for lenses, mirrors, screens, etc.; maximum opening 8×8 cm. (3 required)........Each	1.00
J1326	**Farwell-Stifler Pin Holder,** with set-screw, to fit Sliding Clamp **J1322** (2 required)........Each	.10
J1328	**Ground Glass Screen** (1 mm. thick) 4×7.5 cm.:	
	(*a*) plain	.05
	(*b*) with metric rulings	.15
J1330	**Opaque Screen,** metal, 7.5 cm. square:	
	(*a*) with circular aperture 1.5 cm. diam	.25
	(*b*) with circular aperture and cross-wires	.35
J1332	**Half-meter Stick,** with central slit, for use in measuring wave-length of light	.75
J1336	**Farwell-Stifler Nodal Slide Equipment,** for determining the equivalent focal lengths and nodal points of a combination of lenses. The desired combination is built up from ordinary lenses held in Universal Holders. The special equipment consists of a short metric bar (about 18 cm. long), 2 special narrow Sliding Clamps for holding the Universal Holders, and 1 special Narrow Clamp for supporting the bar (see cut **J1336a**): 2 Elevating Rods are included for lifting the object-screen, etc., to the same height as the Nodal Slide (see cut **J1336b**). The whole arrangement is shown in the cut (Fig. 5). The Nodal Slide Equipment as listed also includes the necessary fourth Universal Holder	2.00
J1145	**Diffraction Grating,** gelatine replica, about 1200 lines per cm	1.50
J9	**Plane Glass Mirror,** 7.5×7.5×cm., high grade	.12
J45	**Spherical Glass Mirror,** concave, 7.5 cm. diameter, 15 cm. focus, with metal rim	1.50
J46	**Spherical Glass Mirror,** convex, 7.5 cm. diameter, 15 cm. focus, with metal rim	1.50
J780	**Lenses with Spherical Surfaces,** Double Convex; 5 cm. diameter, edged and polished; in chamois skin holders:	
	15 cm. focus	.50
	25 cm. focus	.50
	35 cm. focus	.50
J785	**Lenses with Spherical Surfaces,** double concave; 5 cm. diameter, edged and polished; in chamois skin cases:	
	15 cm. focus	.50
	25 cm. focus	.50
J790	**Set of Lenses,** for Optical Bench experiments, including: 3 Double Convex Lenses **J780,** of 15, 25, and 35 cm. focus, and 2 Double Concave Lenses **J785** of 15 and 25 cm. focus	2.25
J48	**Set of Mirrors,** for the Optical Bench experiments, including: Plane Mirror, **J9,** Spherical Concave Mirror **J45** and Spherical Convex Mirror **J46**	3.00
J1340	**Pins,** assorted lengths, white and black heads........Per set	.10