Procedure Title: **Ball Diameter by Interferometry**
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Introduction

There are two Strang Viewers that can be used to make diameter measurements of balls. This procedure will describe both systems; however, the basic principal is the same for both instruments and the differences in use are minor.

The measurement method consists of measuring the distance between two optical flats, one on which the ball is resting and the other on the top supported by the ball. The top flat is held in a fixture so that the flat can be raised and lowered depending on the size of the ball to be measured.

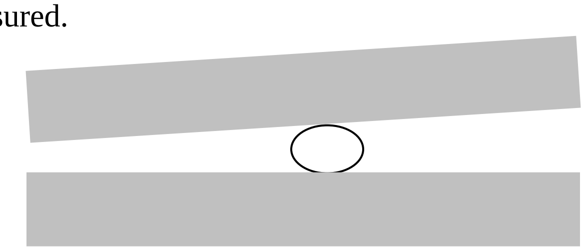


Fig. 1

There must be a wedge between the two flats in order to produce fringes. There also must be provisions for tipping the flat to change the angle between the two flats (wedge angle), and also a provision for tipping the flat in the direction ninety degrees to the wedge angle. The fixtures with the two viewers provide these adjustments.

The setup as shown above is viewed with parallel rays of cadmium light aligned so that the rays are nearly perpendicular to the bottom surface. This setup creates a Fizeau interferometer. Light is reflected off the top of the bottom flat and the bottom of the top flat to create interference fringes. Counting the number of fringes that occur between the two flats gives the distance between the two flats. Because the flats are not parallel, the distance between the flats is different depending where the measurements are made; therefore, one must measure at the point that passes through the center of the ball.

Numerous corrections must be made to the measurement to get the undeformed diameter of the ball. All dimensional measurements are defined at 20 ºC, so if the ball is not exactly at that temperature – and it almost never will be – the actual temperature must be determined and a correction applied for the thermal expansion of the material to get the diameter at 20 ºC.

The wavelength of the cadmium lines used to make the measurement depend on the density of the air through which they pass. The density can be obtained with sufficient accuracy by measuring the temperature, barometric pressure, and the relative humidity (or dew point). The wavelengths of the four colors of cadmium used in the process are defined at either the vacuum wavelength or at the standard metrological conditions of 20 ºC, 760 mm of mercury, and 10 mm of water vapor. A correction must be made for the differences between the actual wavelengths and the standard wavelengths.

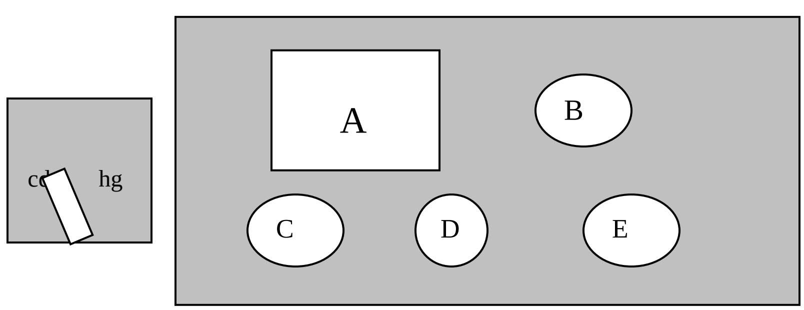
The weight of the flat and the fixture holding the top flat exerts a force on both points where the ball touches the flats. The force on the bottom flat will be larger than at the top because of the weight of the ball. These forces cause elastic deformation to occur at the point of contact. Corrections must be made to get the undeformed diameter of the ball.

Additional corrections must be made for the instrument used to project the cadmium light source creating the fringes. A correction is made because the slit has a finite size (not a point source). An even larger instrument correction is the obliquity correction caused by the fact that the reflected light must return to an opening slightly offset from the point of departure. The instrument corrections are marked on the side of each viewer. They may be verified by measuring a gage block with both the Strang viewer and the Hilger Tyman-Green interferometer using a helium-neon laser as the light source. The difference obtained (assuming negligible uncertainty in the measurement) is the instrument correction of the viewer.

Fixtures, Viewers and Power Supplies

Number 6

The instrument most used is model M # 6 currently in B12 (NIST # 151944). The view from the front appears as in fig. 2. The viewer is equipped to use either mercury or a cadmium source. This procedure will describe using cadmium only as the Group no longer has any mercury cells. The level on the left will always be in the cadmium position. It is clearly marked. The eyepiece (A in figure 2) is equipped with a filar eyepiece for measuring distances between fringes. The eyepiece can also be adjusted to focus at the desired distance. The knob labeled “B” has two positions: microscope and telescope. The microscope position is used in locating the reflected image and to properly adjust the prism to give the desired wavelength. The telescope position is used when viewing the fringe pattern. The knob labeled “C” rotates the prism to properly place the desired color in the field of view. The “D” knob is for setting the slit to the desired light source. It should be set to cd. Knob “E” opens and closes the aperture. During setup the knob is usually in the open position, but must be closed when reading the fringes.



Model M #6 Viewer
Fig. 2

The front of the power supply is shown in figure 3. Because we are using only cadmium as a light source, the right hand or mercury portion of the power supply can be ignored. To turn on the system both of the cadmium power switches must be turned on. Adjust the amperage to 1 to 1.5 amps. Wait about sixty seconds, then turn off switch A (the upper switch). Adjust the power to one amp, or lower if the brightness at one amp is not needed. The brightness of the image increases with the amperage. It is important to time the interval with both switches in the "on" position and not leave to do something else. Leaving both switches on for an extended period of time can damage the light source.

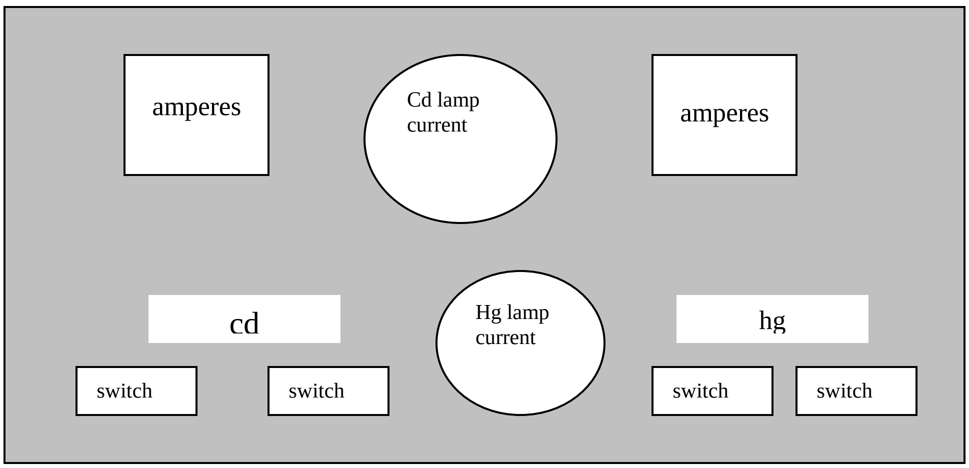


Fig. 3
Power supply with viewer # 6

To best prolong the life of the cadmium bulb, the power should be left on during the day while the instrument is being used with the power at the lowest amperage needed. The instrument should be turned off for any extended period of time when not in use. Turn it off at the end of the day and then back on again the next morning if the instrument is being used for more than one day.

Number 1
Model F12-M #1 (NIST #165922) is currently in room B18. There are some differences between the two instruments. Looking at the instrument from the top, the light source holder can be moved to four locations labeled hg. 198, Ger. Osram, Cenco, with the fourth position blank. The position is set to German Osram when using the cadmium source. The parts of the instrument are listed below with the appropriate letters shown in figure 4.

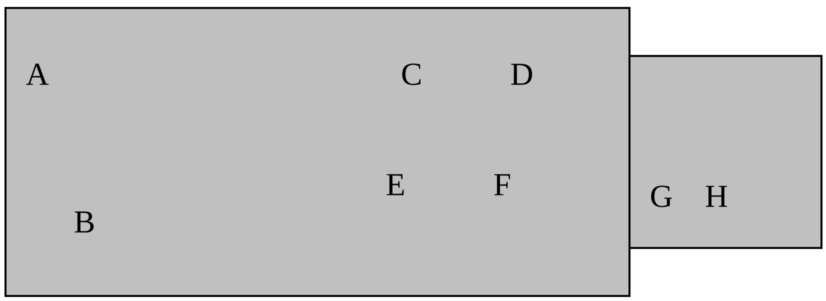
A ext. and mercury set to ext.
B bubble level There is a bubble level for leveling the machine. There is another on top for leveling in the ninety-degree position.
C eyepiece for viewing the reflections and reading the fringes
D knob for setting the slit width for the appropriate source
E knob for setting the slit height for the appropriate source

F knob for switching between microscope and telescope The microscope position is used in locating the reflected image and to properly adjust the prism to give the desired wavelength. The telescope position is used when viewing the fringe pattern.

G knob to rotate prism to get desired color (proper wavelength)

H crank for changing from mirror to prism position. When using cadmium, use prism setting.

The power supply is also slightly different in the two models, but they are interchangeable. The one used with viewer model #1 could be used with viewer model #6 and vice versa.



Model F12-M #1 Viewer
Figure 4

The power supply currently with viewer model # 1 is equipped with two inputs. The output switch shown in figure 4 must be set to the correct cable input to the viewer located on the back of the power supply.

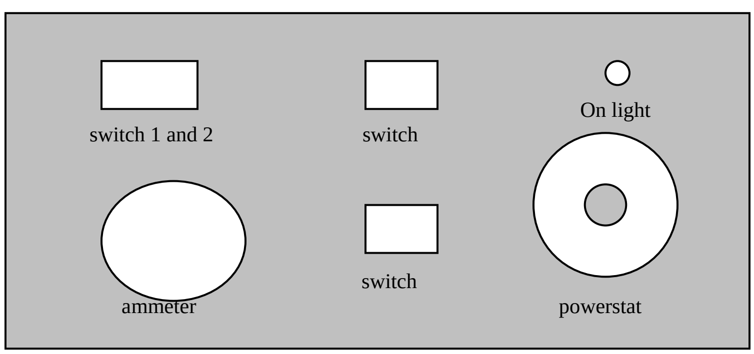


Figure 5
Power supply with viewer # 1

The switches on this power supply are clearly marked. Follow the instruction written on the front of the case when turning on this instrument. Again leave both switches on about sixty seconds and then do not forget to turn off the start switch.

Optical Flat Holding Fixture

The fixture must have a pivot point between the optical flat and a counterbalance to allow for setting the desired force on the top flat. The fixture must be capable of adjustment to make the top flat nearly parallel with the bottom flat. It must also have means of moving the flat up and down in order to measure various sized balls. The fixtures currently available have a 40-pitch thread in the up and down movement. This means that one revolution of the knob raises or lowers the fixture 0.025 inches. When changing from one size to the next counting the number of turns allows one to get almost exactly the correct height for the next ball size.

Aligning the Instrument

If the instruments are moved they may need realignment. It is necessary for the light rays to be nearly perpendicular to the top of the bottom flat used in making the ball measurements. Start by leveling the table so that it is perpendicular to the gravity vector. (This is not absolutely necessary, but it makes both the alignment and the use of the instrument easier.) Align the instrument using the bubble levels so that it is parallel to the tabletop. Next place a mirror or a steel platen on the top of the table or desk on which the viewer is used. The optical flat used to make the measurements could be used but if the two surfaces are not parallel, two images may be seen. The bottom image can be eliminated by covering the bottom surface with Vaseline or other oil having about the same density as quartz. With the switch in the microscope position and the slit open, look for an image from the reflecting surface. This may take some time, as you must move the X and Y orientations of the instrument to get the proper alignment. If the bottom flat is not supported on the table but rather supported on another device, it makes the alignment even more difficult, but the procedure is the same. The light rays must be perpendicular to the top of the bottom surface.

Next place the fixture holding the top flat as show in figure 1 above the bottom flat and adjust the fixture so that the bottom of the top flat is nearly perpendicular to the light source. In is necessary for the top flat to have a wedge angle between the two surfaces; otherwise, it will not be possible to separate the images from the top of the top flat from the image off the bottom of the top flat.

Measuring the Force

There are two different methods to measure the force on the ball. Although the initial setup may be a bit more difficult, the most accurate and easiest to use method is to support the bottom flat on a precision scale (balance). With the top flat not touching the bottom flat and nothing on the bottom flat, use the floating zero button to set the reading to zero. Next place the ball to be measured on the flat and measure the weigh of the ball, which is also the force exerted at the bottom of the ball causing some deformation of the ball and flat. Next place the top flat in contact with the top of the ball with the fixture set to exert approximately the desired force. A reading is again taken which gives the combined force of the top force pushing down and the force due to the weight of the ball. This number is used to calculate the deformation at the bottom of the ball. The total force minus the force due to the weight of the ball is used to calculate the deformation at the top of the ball. Four ounces (about one Newton) is a reasonable value for most measurements. A smaller force would be used for very small balls and in some cases one may want to use a larger force for larger balls. The important thing is to remain well below the elastic limit of the ball deformation. The deformation can be determined using the Hertzian equations given in Puttock and Thwait's book or they can be gotten using Jay Zimmerman's program "Elastic."

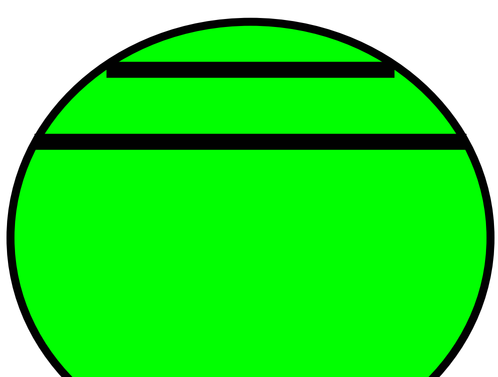
If the material properties of the ball to be measured are not well known, several measurements can be made at different forces to determine the correction for the undeformed diameter. For measurements of the highest accuracy this method should be employed even if one thinks the properties are known.

The alternate method does not use the scales. The bottom flat is placed directly on top of the table or desk supporting the fixture and viewer. The ball is weighed separately to determine the force it will exert downward. The top force is determined using a dynamometer to measure the downward force on the ball. The problem with this method is that one must measure the force at exactly the point on the flat where the ball will be placed. This can be done by marking a thin line on the top of the flat or by choosing a scratch on the flat in an area near the center of the flat. The ball then must always be positioned under this marking at the spot where the force was measured. The advantage of having the flat directly on the scale is that it allows for the ball to be positioned nearly anywhere within the field of view – although it is best to position it near the center of the field of view.

The force readings using the dynamometer are not accurate unless the dynamometer has been recently calibrated. The calibration can be made using weights suspended on a thin thread. Note that some of the dynamometers read in two directions, each of which would give a different reading. The dynamometer must be used in the same direction that it was calibrated.

Preparations for making a Measurement

Following the initial alignment of the instrument, the ball to be measured in carefully placed between the two flats. Some adjustment will again be necessary to get fringes. Start using the green line of cadmium, as it is the easiest to see. With the slit open and the top flat nearly parallel to the bottom flat, make the necessary adjustment to get the image from the top of the bottom flat and the bottom of the top flat to overlap. Then make the necessary adjustments so one can see the reflected image when the slit is closed. Next switch to telescope and view the fringes. Addition adjustments will be necessary to get the desired spacing between the fringes and to get the correct orientation of the fringes. Some thought also must be given to the position of the open end of the wedge. It is customary (though not necessary) to have the open end of the wedge at the top of the field of view. The view would look somewhat similar to figure 6.



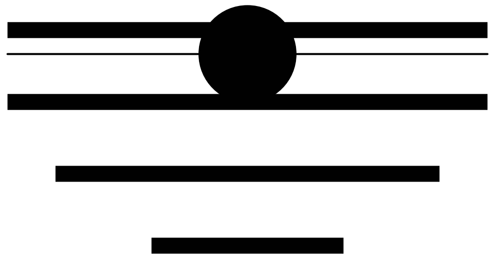


Figure 6
View of fringes

The actual fringes will not be as clear and sharp as shown in the picture. The dark circle in the middle is the ball to be measured. The ratio of the size of the ball to the field of view will be dependent on the ball size. A 50-mm ball will occupy almost the entire field of view. The thin black line is a moveable reticule line. It should be set to the center the ball when estimating the fringe fraction. Rather than estimating the center, a reading may be made with the reticule line at the top of the ball and another at the bottom. Calculate from those readings the position of the centerline. Assuming we have set the open end of the wedge at the top of the field of view, the goal next is to determine the ratio of the distance from the line through the center of the ball to the fringe below the ball divided by the distance between the two fringes (the one above and the one below). For example, in figure 6 the ratio appears to be somewhere between 0.60 to 0.65

If we had placed the open end of the wedge at the bottom of the field of view, the fringe fraction would be taken in the opposite direction, i.e., it would be between 0.35 and 0.40.

The reason for determining the fringe fraction is to compute the total number of fringes plus the fringe fraction between the top of the bottom flat and bottom of the top flat. This number will be very large; the distance between the fringes is equal to one half of the wavelength of light, which for the green cadmium line is about 500 nanometers. If we know the approximate size of the ball (within 100 microinches), and if we measure the fringe fraction between the flats for all four of the wavelengths of the cadmium line, we can calculate the number that precedes the fraction for each of the reading of the four colors