Refractometer for Visitor Center

Description

A refractometer is used to determine the index of refraction of substance, i. e. how much it will bend a light beam. The index of refraction can indicate the density or composition of the substance. For example, a refractometer can determine the difference between fresh water, which has an index of refraction of 1.333, and sea water whose index of refraction is 1.3393.

This instrument was designed to be a stand-alone exhibit in our visitor center. The exhibit was expected to be unattended and open to all visitors. The signage had to be completely self-explanatory and the exhibit itself had to be built as solidly as possible. Fig 1 is a picture of the completed exhibit.

Figure 1

Construction

CONSTRUCTION NOTES:

This is how we did it. We made some of it up as we went. You will, no doubt, find many things you can improve upon.

Materials:

- ½ inch 2A plywood for base as shown in Fig 3 (4 X 8 sheet is enough for 3 bases). The extras are good if you mess one up.
- 1 X 2 inch wood (we used hardwood, as that was what we had in the garage), for the slide base, the laser cradle and the slide handles. See Fig 2.
- 1/8 by 4 inch wood for the base of the prisms (plastic would probably work as well). See Fig 2.
- 3 hollow prisms, equilateral, 60 degree angles.
- Plexiglas strip 30" x 3" x 1/8"
- Laser pointer.
- Rubber feet for bottom of base board.

The hollow prisms are available from:
Cynmar Corporation, 1-(800) 223-3517, www.cynmar.com

Laser pointers are available from Staples, www.staples.com

All the other materials are available at the local lumber or hardware store.

The total cost for the project is < $100, including the prisms and laser.

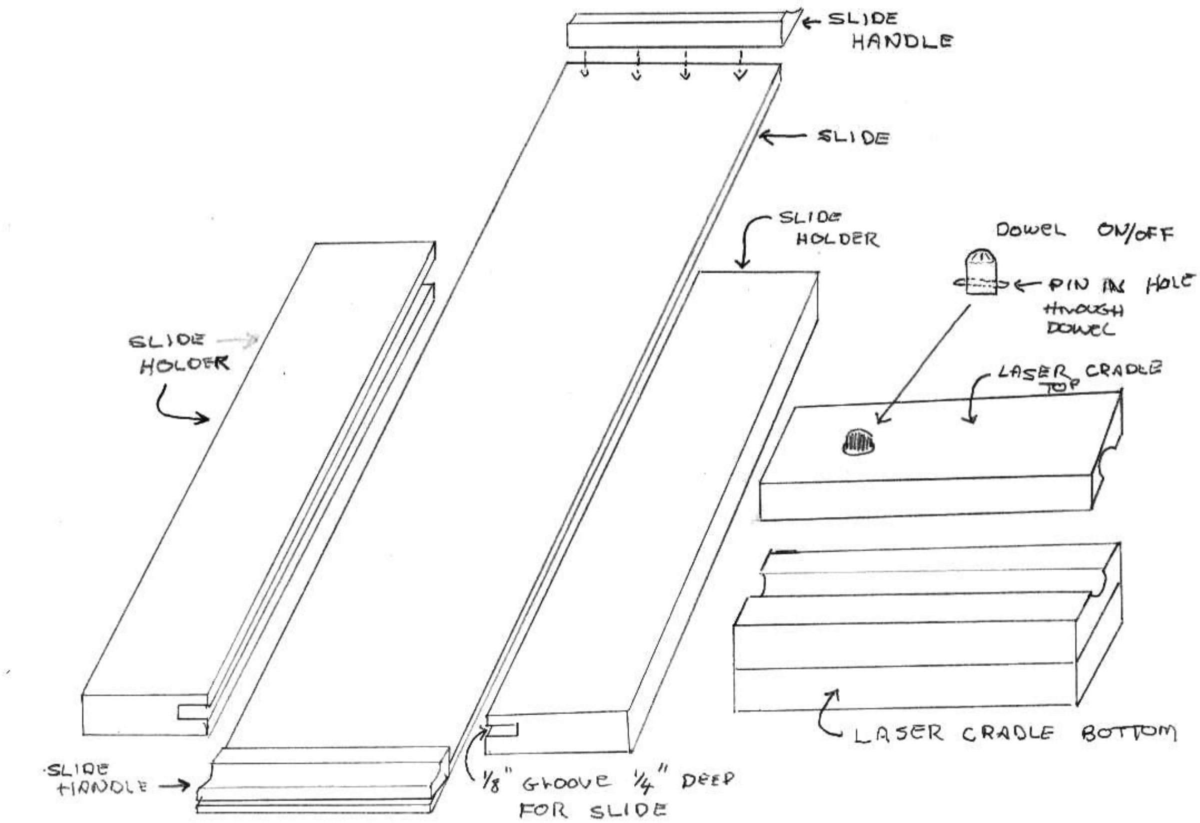


Fig 2
Detail of prism slide and laser cradle.

Our dimensions were:

Slide 1/8 X 4 X 12 inches

Slide handles (need to go all the way across the slide to prevent the slide from being pulled out of the side holders) 1 X 1 X 4"

Slide holders 1 X 2 X 5 inches (we used a 1/8 inch thick dado to cut the grooves for the slide)

Laser cradle 6" long (we used the same 1 X 2 to construct this by gluing two pieces on the bottom together to get the laser high enough to clear the slide holders, we dadoed a ½ inch groove in the top of the base and the bottom of the top piece to firmly hold the laser in place. The batteries can still be changed on the laser without having to remove it from the cradle.

We placed a 3/8 inch piece of dowel in a hole we cut in the top of the laser cradle directly over the on/off button on the laser. The spring tension on the laser is enough to lift the dowel and turn the laser off to prevent the batteries from prematurely running down. See Fig 4.

NOTES AND TIPS (See Fig 3)

All screws were from the underside of the base so that nothing is showing (I think it just looks better). It also improves the security, as the first laser was stolen! This is the second design and the laser cannot be moved!

The base board was finished off with white paint and Varithane to protect it against possible spills.

The target for the laser is 1/8 X 3 inch Plexiglas which we cut to fit in a groove we made in the shape of an arc one meter from the center of the prisms. We made the groove by a router placed on the end of a scrap piece of lumber cut such that the radius from the center to the groove was one meter exactly. We nailed the board to the pivot point and wired the router to the board

The Plexiglas was sprayed white and the degrees marks are 17.45 mm per degree (circumference = pi X diameter / 360). We got 1 inch letters (from Staples) for the numbers and 1/8 inch auto pin stripes (from Napa) for the marks. The Plexiglas was glued into the curved slot. See Fig 5.

The laser beam is probably not aligned with the body of the laser. You will probably need to place small layers of wood, cardboard or tape in the laser cradle to act as shims. The laser beam must fall on the zero point of the angle scale when not passing through a prism.

We secured the small piece of dowel used to turn on the laser by drilling a small hole through it, placing a finishing nail through it cutting off the ends leaving 1/8 inch on either side and cutting a small slot in the bottom of the top piece of the laser cradle to prevent this from being stolen (by now, we are quite cynical).

We glued the prisms to the slide as shown in the picture and glued a piece of plastic to connect all three. I refilled one of the prisms, which involved drilling a small hole and using a needle and syringe to refill. Bolts were added to help secure the plastic top strap for the prisms. See Fig 6.

The placement and orientation of the prisms requires some adjustment. The figures in the table under Operation assume that:

1) The corner angles of the prisms are exactly 60 degrees.
2) The prisms are oriented exactly "upright", with the centerline perpendicular to the laser beam, as shown in Fig 8.

Neither of these conditions is likely in actual practice. The simplest way to resolve this problem accurately is to orient the prism before the glue is set, so the correct angle is achieved.

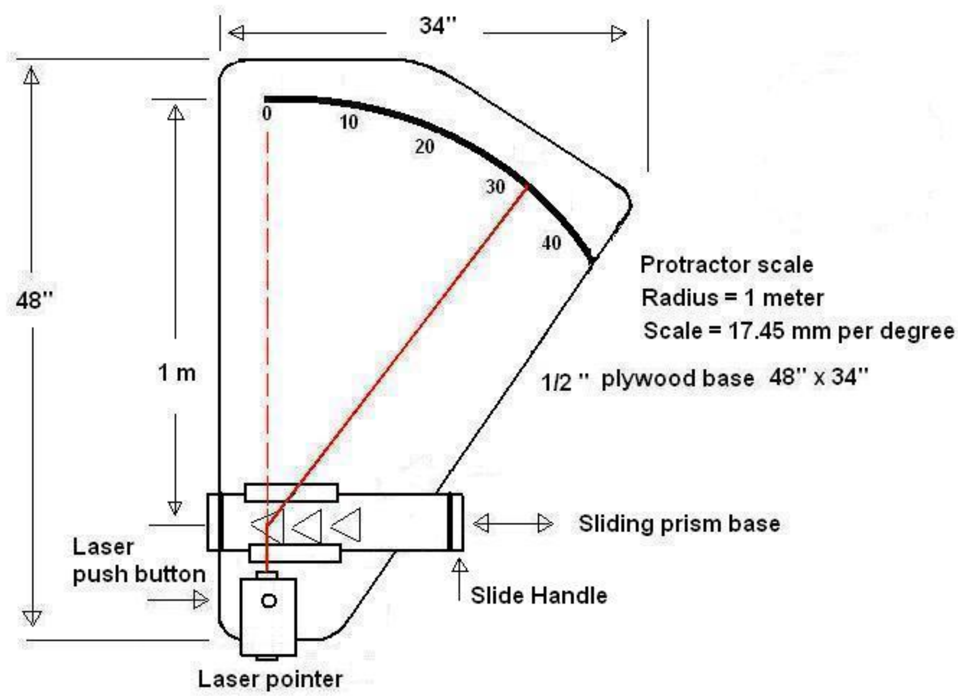


Fig 3
Simplified "floor plan" of Refractometer

When the prisms are not in place, the laser beam must fall on the zero point on the angle scale. You may need to place shims in the laser cradle to align the beam properly.

Fig 4
Finished prism slide, slide holders and laser cradle

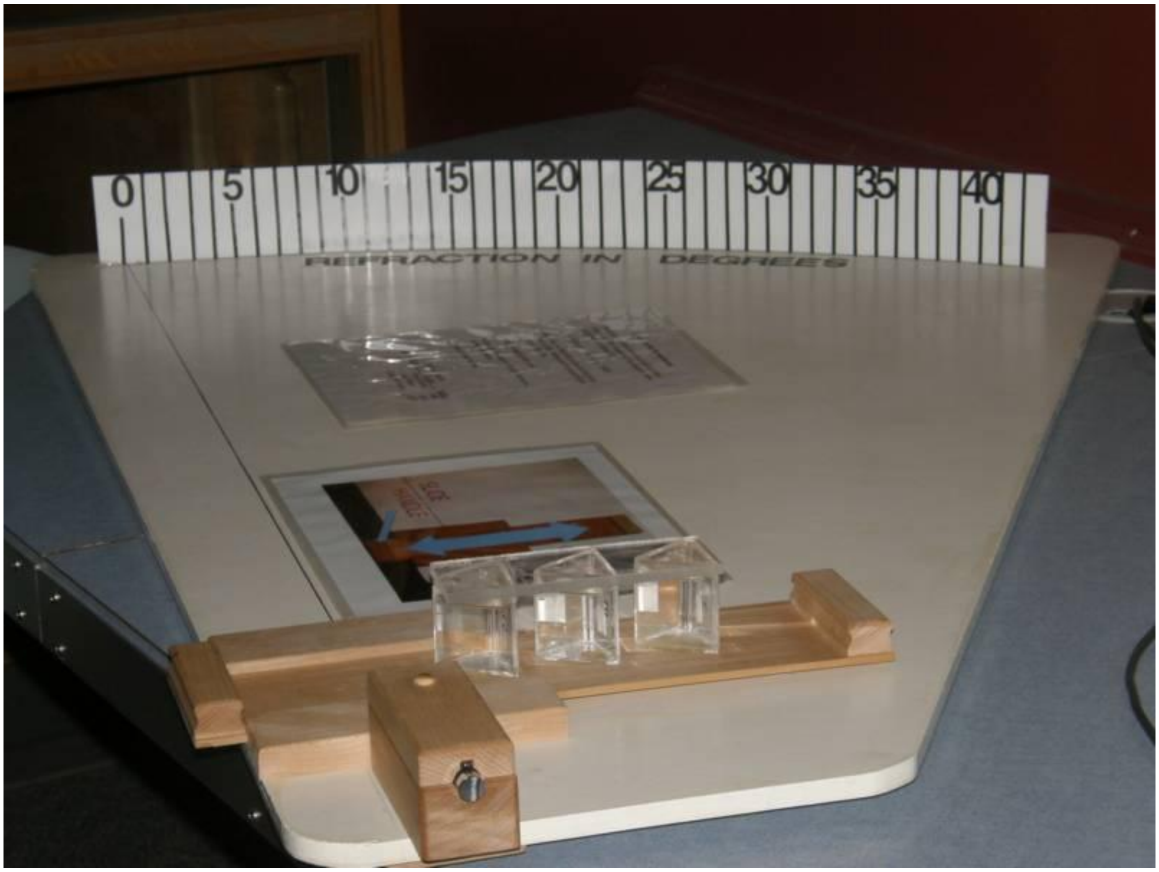


Fig 5
Angle scale and attached signage

Fig 6
Detail of prisms, top strap and bolts

Operation

The operation of this instrument is designed to be a simple as possible. No assembly required, nor any math either.

- Press the button to turn on the laser pointer. See Fig 7.
- Move the slide so that one of the prisms is in the path of the beam. Adjust the slide so that the beam forms a sharp dot on the angle scale.
- Read the angle. Try to estimate the reading to a 1/10 of a degree, if possible. It may be helpful to take several readings and average them.
- Repeat for each of the 3 prisms.
- Compare the measured angles to the following table, and identify the fluids and their characteristics.

Measured Angle	Index of Refraction	Salinity %	Example
25.10	1.333	0	Fresh water
25.69	1.339	3.5	Sea Water
26.72	1.350	9.5	Great Salt Lake
30.83	1.390	31.82	Dead Sea
32.29	1.4031	39.13	Max concentration

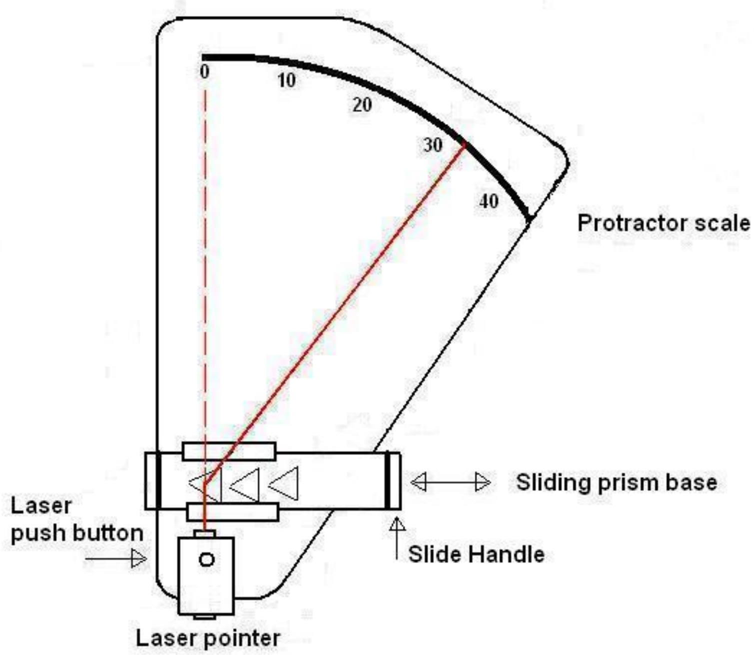
See Appendix 1for the formulas used in this table.

Fig 7
Refractometer in operation
The angle shown is about 27.1 degrees

Exhibit Signage – attached directly to the base board

Refractometer

A refractometer is a device that measures the angle that a light beam is bent (angle of refraction), in this case, by a liquid-filled prism. The angle helps to identify the liquid.



The major components of the refractometer are:

- A laser pointer to produce the light beam.
- A set of liquid-filled prisms mounted on a sliding base.
- A large angle scale (protractor) which measures angles in degrees.

How it works

The laser produces a narrow beam of light which falls on the prism and is bent through a specific angle, called the angle of refraction. This bending is because the speed of light in the prism is less than the speed of light in air.

This angle is determined by the density and other characteristics of the liquid in the prism.

The laser beam falls on the angle scale, really just a large protractor.

The angle identifies the liquid in the prism.

How to use the Refractometer

This device measures how much salt is in these water samples by measuring the amount a beam of light is bent (refracted).

- Press the button on top of the laser.
- Move the wooden slide to line up a prism with the laser. Adjust until a sharp point of light appears on the scale.
- Read the angle on the scale.
- Compare the angle to the table below to identify the kind of water and it's characteristics.
- Repeat for each prism.

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Appendix 1

This appendix presents the prism geometry and the formula for the angle of refraction (T) in terms if the index of refraction (n).

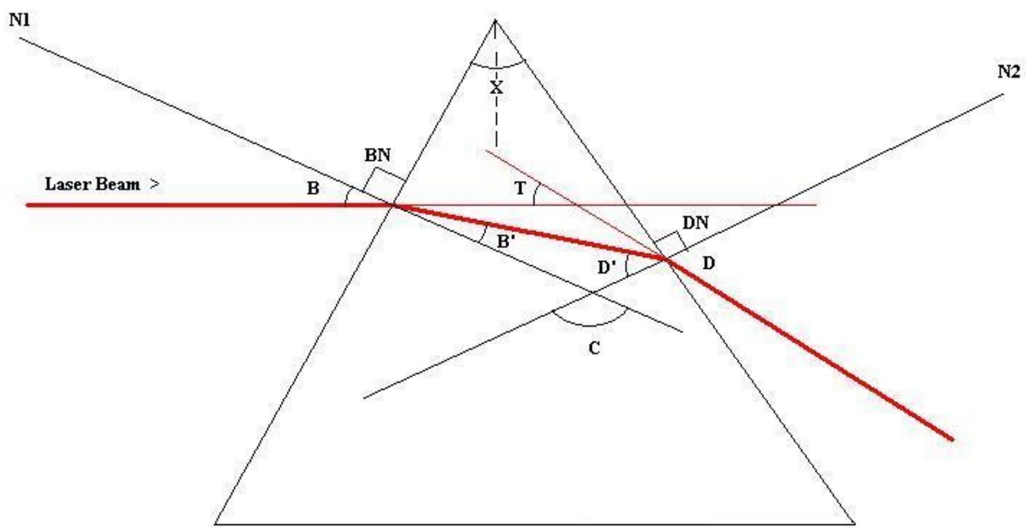

Fig 8
Geometry of the laser beam and prism in the normal ("upright") position.

The heavy red line is the path of the laser beam, going from left to right. The thin red lines are extensions of the exterior laser beam inside the prism. Lines N1 and N2 are normals constructed perpendicular to the prism sides. These serve as reference lines for measuring various angles. Angles BN and DN are right angles. The dashed line at the top of the prism is vertical, dividing the angle X in half. This dashed line must be perpendicular to the incoming laser beam.

The basic formula used is to calculate:

- T, the total angle of refraction

Given:

- X, the vertex angle of the prism.
- n, the index of refraction of the fluid in the prism.

The formula is derived as follows.

$B = X / 2$	BN is a right angle
$T = D - X / 2$	DN is also a right angle
$\sin(B') = \sin(B) / n$	definition of the index of refraction
$B' = \arcsin(\sin(B) / n)$	
$\sin D = n * \sin(D')$	
$D = \arcsin(n * \sin(D'))$	
$X + BN + C + DN = 360$	interior angles of a quadrilateral sum to 360
$X + C = 180$	$BN + DN = 180$
$C = 180 - X$	
$B' + C + D' = 180$	interior angles of a triangle sum to 180
$D' = 180 - C - B'$	
$D' = 180 - 180 + X - B'$	
$D' = X - B'$	
$T = D - X / 2$	now put it all together
$T = \arcsin(n * \sin(D')) - X / 2$	
$T = \arcsin(n * \sin(X - B')) - X / 2$	

$$\mathbf{T = \arcsin(n * \sin(X - \arcsin(\sin(X / 2) / n))) - X / 2}$$

The salinity of the sample is calculated as follows:

$$\mathbf{S = 558 * n - 743.8}$$

Where S is the salinity in percent of salt by weight, and "n" is the index of refraction. This empirical formula was derived from a table of sodium chloride solutions in the Handbook of Chemistry and Physics, 70^{th} ed, pp D-255, D-256.