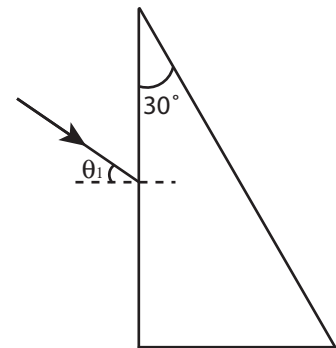


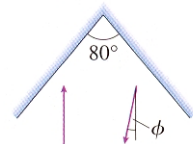
Problem Session

1. You're helping with an experiment in which a vertical cylinder will rotate about its axis by a very small angle. You need to devise a way to measure this angle. You decide to use what is called an optical lever. You begin by mounting a small mirror on top of the cylinder. A laser beam 5.0 m away shoots a laser beam at the mirror. Before the experiment starts, the mirror is adjusted to reflect the laser beam directly back to the laser. Later, you measure that the reflected laser beam, when it returns to the laser, has been deflected sideways by 2.0 mm. How many degrees has the cylinder rotated?

2. The prism in the following figure is made out of glass with an index of refraction of $n = 1.50$.
- What is the smallest angle θ_1 for which a laser beam will undergo total internal reflection on the hypotenuse of this glass prism?
 - After reflecting from the hypotenuse, the laser beam exits the prism through the bottom face. Does it exit to the right or the left of the normal? At what angle?

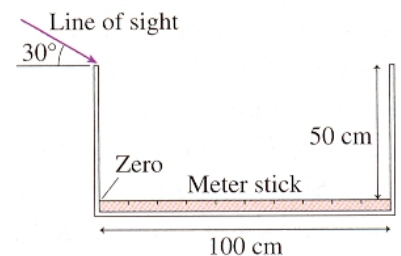


3. **Reflection.** A laser beam is incident on the left mirror in the figure below. Its initial direction is parallel to a line that bisects the mirrors. What is the angle ϕ of the reflected laser beam?



4. **Refraction.** An underwater diver sees the sun 50° above horizontal. How high is the sun above the horizon to a fisherman in a boat above the diver?

5. A meter stick lies on the bottom of a 100-cm-long tank with its zero mark against the left edge. You look into the tank at a 30° angle, with your line of sight just grazing the upper left edge of the tank. What mark do you see on the meter stick if the tank is



- empty,
- completely full of water ($n = 1.33$).

6. **Colour and dispersion.** A narrow beam of white light is incident on a sheet of quartz. The beam disperses in the quartz, with red light ($\lambda \approx 700$ nm) traveling at an angle of 26.3° with respect to the normal and violet light ($\lambda \approx 400$ nm) traveling at 25.7° . The index of refraction of quartz for red light is 1.45. What is the index of refraction of quartz for violet light?

7. **Image formed by multiple lenses.** Two converging lenses with focal lengths of 40 cm and 20 cm are 10 cm apart. A 2.0-cm tall object is 15 cm in front of the 40-cm-focal-length lens. Calculate the image position and height.

8. A converging lens with a focal length of 40 cm and diverging lens with a focal length of 40 cm are 160 cm apart. A 2.0-cm tall object is 60 cm in front of the converging lens. Calculate the image position and height.
9. **Image formed by refraction.** A biologist keeps a specimen of his favourite beetle embedded in a cube of polystyrene plastic ($n = 1.59$). The hapless bug appears to be 2.0 cm within the plastic. What is the beetle's actual distance beneath the surface.

Answers

1. $\Delta\theta = 1.15 \times 10^{-2}$ degrees
2. a) 17.88° , b) 27.9° left of normal.
3. $\varphi = 20^\circ$
4. 31.3°
5. a) 86.6 cm, b) 42.9 cm
6. $n = 1.48$
7. the real image is 48.57 cm to the right of the 20 cm lens, and is 4.57 cm high and inverted.
8. the virtual image is 20 cm to the left of the diverging lens, and is the same height as the object but inverted.
9. 3.18 cm below the surface.