Thinking Like a Physicist

PHYS 2302, Saint Mary's University D. A. Clarke, August 2020

<u>*Scenario 1*</u>

On your bicycle, you feel a headwind. But is it really a *head*wind, or is it just because you are going 25 km/hr?

a) How can you tell which way the wind is blowing relative to the ground without stopping?

b) If you didn't mind stopping and going in various directions for a bit, how might you tell how fast the wind is actually blowing? (Assume you have a bike computer that tells you how fast you're travelling.)

Suggested solution:

a) Tree swaying tends to be back and forth, regardless of wind direction, so this is perhaps not the best indicator. Leaves blowing across the ground? Ripples across a field of grass you may be passing?

b) Find a parking lot, and ride your bike in the direction and at a speed at which you feel no wind. That's the direction and speed of the wind relative to the ground.

Scenario 2

You're crossing a bridge over a babbling brook with your date and you get distracted by wondering how much water flows under it per second. How might you do this and remain in keeping with the "romantic moment"?

Suggested solution:

Play Pooh sticks!!

Time the sticks (in your head; for goodness sake, don't let on you're doing physics!!) to go under the bridge. Suppose $t = 5\,\mathrm{s}$.

As you cross the bridge to see whose stick arrives first, (secretly) pace it. Suppose it's width is $W = 5\,\mathrm{m}$.

A quick estimate of the brook width, w, and depth, d (*e.g.*, $10\,\mathrm{m}$ and $0.5\,\mathrm{m}$) and a quick calculation leads to a flow rate f of,

$$f = \frac{Wwd}{t} = \frac{(5)(10)(0.5)}{(5)} = 5.0\,\mathrm{m}^3\,\mathrm{s}^{-1} \sim 5{,}000\,\mathrm{l}\,\mathrm{s}^{-1}.$$

Ta-da!!

Scenario 3

You're stopped at a traffic light beside some hotshot in a souped up 'stang just busting to drag you once the light turns green. Alas, your poor old K-car from the 90s is not up to the challenge, so instead you decide to figure out how much friction (μ_s) the road exerts on his tires!

Assuming the kid knows how to maximise his acceleration (*i.e.*, by occasionally chirping but not squealing his wheels, he maintains static friction with the road instead of the lesser kinetic friction), what data do you need to estimate μ_s?

Suggested solution:

If the intersection width is $d = 10\,\mathrm{m}$ and the time it takes the 'stang to cross the intersection $t = 2\,\mathrm{s}$, then kinematics tell us,

$$a = \frac{2d}{t^2} = 5\,\mathrm{m\,s^{-2}},$$

and, remembering it's the friction force on the tires that accelerates the car, Newton's second law tells us,

$$\mu_\mathrm{s} m g = m a \quad \Rightarrow \quad \mu_\mathrm{s} = \frac{a}{g} \sim \frac{1}{2}.$$

Isn't physics wonderful?!?

Scenario 4

You see a buoy bobbing up and down in the water, and you wonder how heavy it is. What data do you need to estimate its mass?

Suggested solution:

Restoring force (which we learned from our discussions on oscillations) is,

$$-\rho A z g \;=\; m\ddot{z} \quad \Rightarrow \quad \omega^2 \;=\; \frac{\rho A g}{m} \;=\; \frac{4\pi^2}{T^2}.$$

For $T \sim 1\,\mathrm{s}$, $A = \pi r^2 \sim 0.03\,\mathrm{m}^2$ ($r \sim 0.1\,\mathrm{m}$), and $\rho = 10^3\,\mathrm{kg\,m^{-3}}$,

$$m \;=\; \frac{\rho A \not{g} T^2}{4 \not{\pi^2}} \;\sim\; 7.5\,\mathrm{kg},$$

or about $75\,\mathrm{N}$ ($\sim 17\,\mathrm{lb}$; conversion from $\mathrm{N} \rightarrow \mathrm{lb}$ is about 0.225, or 0.2 for rough estimates).

Scenario 5

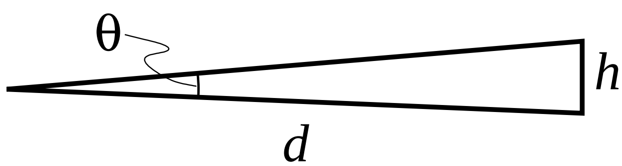
You're doing 20 km/h on your bike, and a woman passes you at what seems to be a good clip. You're curious how fast she is actually going. What data do you need to estimate her speed, and how do you get them?

Suggested solution:

Field-astronomy tip: a fist held out at arm's length subtends an angle of about 10°, and a finger held out at arm's length subtends an angle of about 1.5° (three full-moon widths).

So, hold two fingers out horizontally to cover part of the advancing rider, and count how long it takes for these to cover her completely. One-one-thousand, two-one-thousand, *etc.*

Two finger-widths $\sim 3^\circ \sim 0.05\,\mathrm{rad}$, thus rider is $1/0.05 = 20$ times as far away as she is high (say 1.5 m), thus 30 metres.



$$h = d\theta; \quad \frac{d}{h} = \frac{1}{\theta}$$

If you count to six-one-thousand, her relative speed is $30/6 = 5$ m/s. Multiply by 3.6 to get 18 km/hr, and rider passed you at 38 km/hr.

Scenario 6

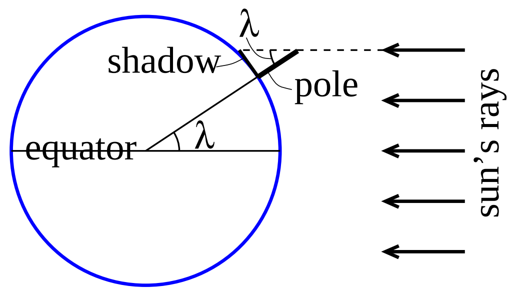
Eratosthenes redux. In Halifax at high noon on the autumnal equinox (~ 1 pm), you measure the shadow's length of a 10 m tall perfectly vertical flagpole to be 9.88 m. You tell your buddy in Summerside, P.E.I. of your measurement, and he says: "What a coincidence! I too measured the shadow's length of our perfectly vertical 10 m tall flagpole at high noon on the equinox, and it was 10.50 m; you must have made a mistake!"

But the physicist in you knows better. Given that Summerside is 200 km due north of Halifax, what is the circumference of the Earth?

Suggested solution:

At high noon on the equinox, the sun's rays are parallel to the equator and shadows point due north. Thus, the tangent of the latitude is the ratio of the shadow length to the pole height:

$$\lambda_{\rm S} \;=\; \tan^{-1}(1.050) \;=\; 0.810\,\text{rad};$$
$$\lambda_{\rm H} \;=\; \tan^{-1}(0.988) \;=\; 0.779\,\text{rad}$$
$$\Rightarrow \quad \Delta\lambda \;=\; 0.031\,\text{rad}.$$



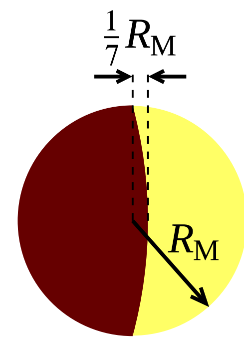
Then using the scaling law,

$$\frac{\Delta\lambda}{2\pi} \;=\; \frac{d_{\rm H\to S}}{C_{\rm E}} \quad \Rightarrow \quad C_{\rm E} \;=\; (200\,\text{km})\frac{2\pi}{0.031} \;=\; 40{,}500\,\text{km}.$$

(Accepted value is 40,075 km; 1.1% error.)

Scenario 7

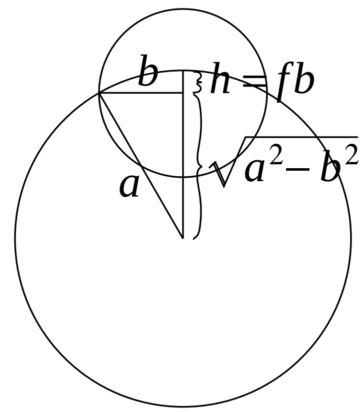
On an evening of a total lunar eclipse, you observe the Earth's shadow as it crosses the moon and note that at the half-way point, the shadow's curvature eats into the still-lit side of the moon by 1/7 of the lunar radius. What is the diameter of the moon, and how far away is it?



You may use the result from *Eratosthenes redux* where we found the circumference of the Earth to be 40,500 km. What other datum do you need to find its distance, and how do you measure it?

Suggested solution:

In the diagram, $a = R_{\mathrm{E}}$, $b = R_{\mathrm{M}}$, and $h = fb$ is the distance the Earth's shadow eats into the still-lit side of the moon. Thus, $f = \frac{1}{7}$. It is now just a matter of a little geometry and algebra:



$$h \;=\; fb \;=\; a - \sqrt{a^2 - b^2}$$

$$\Rightarrow \quad \cancel{a^2} - b^2 \;=\; (a - fb)^2 \;=\; \cancel{a^2} - 2afb + f^2b^2$$

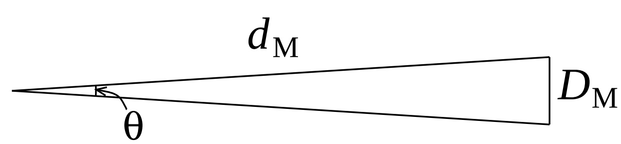
$$\Rightarrow \quad b^{\cancel{2}}(1 + f^2) \;=\; 2af\cancel{b} \quad \Rightarrow \quad \boxed{b \;=\; a\frac{2f}{1+f^2}.}$$

Thus, for the problem at hand,

$$D_{\mathrm{M}} \;=\; 2R_{\mathrm{M}} \;=\; D_{\mathrm{E}}\,\frac{2/7}{1+\frac{1}{49}} \;=\; D_{\mathrm{E}}\,\frac{7}{25} \;=\; \frac{40{,}500}{\pi}\,0.28 \;=\; \underline{\underline{3{,}610\,\mathrm{km}}}.$$

(Accepted value is 3,474 km; 3.8% error.)

$$\theta \;=\; \frac{D_{\mathrm{M}}}{d_{\mathrm{M}}} \quad \Rightarrow \quad d_{\mathrm{M}} \;=\; \frac{1}{\theta}\,D_{\mathrm{M}}.$$



Raising your index finger against the full moon, you find it to be $\sim 1/3$ your finger width, and thus subtends an angle of $\theta \sim 0.5^\circ \sim 0.0087\,\mathrm{rad}$. Thus the moon is $(0.0087)^{-1} \sim 115$ times as far away as its diameter,

$$d_{\mathrm{M}} \;\sim\; 115\,D_{\mathrm{M}} \;\sim\; (115)(3{,}610) \;=\; 4.15 \times 10^5\,\mathrm{km}.$$

(Accepted value is 405,684 km; 2.3% error.)