On speed

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Warm-up problems

1. What is the formula linking the *average speed* of an object, the *distance* it has travelled, and the *time taken*? Don't forget to say what any symbols you use mean, and what units they are normally measured in.

the *average speed*
unit: **metre per second** (m/s)

the *total distance travelled*
unit: **metre** (m)

$$v = \frac{d}{t}$$

the *time taken*
(end time − start time)
unit: **second** (s)

2. Give at least three common units of measurement of speed and show how values for speed in these units can be converted into values in the usual unit used in physics.

- kilometers per hour (km/h)

$$\frac{1\,\cancel{\mathrm{km}}}{\cancel{\mathrm{h}}} \times \frac{1000\,\mathrm{m}}{\cancel{\mathrm{km}}} \times \frac{\cancel{\mathrm{h}}}{60\,\cancel{\mathrm{min}}} \times \frac{\cancel{\mathrm{min}}}{60\,\mathrm{s}} = 0.278\,\mathrm{m}\ /\ \mathrm{s}$$

- miles per hour (km/h)

$$\frac{1\,\cancel{\mathrm{mi}}}{\cancel{\mathrm{h}}} \times \frac{1600\,\mathrm{m}}{\cancel{\mathrm{mi}}} \times \frac{\cancel{\mathrm{h}}}{60\,\cancel{\mathrm{min}}} \times \frac{\cancel{\mathrm{min}}}{60\,\mathrm{s}} = 0.444\,\mathrm{m}\ /\ \mathrm{s}$$

- knot (kn or kt)

$$1\,\mathrm{kn} = \frac{1\,\cancel{\text{nautical mile}}}{\cancel{\mathrm{h}}} \times \frac{1852\,\mathrm{m}}{\cancel{\text{nautical mile}}} \times \frac{\cancel{\mathrm{h}}}{60\,\cancel{\mathrm{min}}} \times \frac{\cancel{\mathrm{min}}}{60\,\mathrm{s}} = 0.514\,\mathrm{m}\ /\ \mathrm{s}$$

Regular problems

3. Thunder from a distant electrical storm is heard 8 s after the lightning. If sound travels at 340 m/s, how far away is the point where the lightning happened?

$$\begin{aligned} d &= v \times t \\ &= 340\,\mathrm{m/s} \times 8\,\mathrm{s} \\ &= 2720\,\mathrm{m},\text{ or } 2.7\,\mathrm{km}. \end{aligned}$$

4. Find the average speed of Mr Townsend in the men's quadruple scull in heat 2 of the 2016 Rio olympics. Their time was 5:52.770 over a 2000 m course.

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{2000\,\mathrm{m}}{5\,\cancel{\mathrm{min}} \times \frac{60\,\mathrm{s}}{\cancel{\mathrm{min}}} + 52.77\,\mathrm{s}} \\ &= \frac{2000\,\mathrm{m}}{352.77\,\mathrm{s}} \\ &= 5.67\,\mathrm{m/s}. \end{aligned}$$

5. A laser beam can be bounced off the Moon (from a retro-reflector left by astronauts). The light travels there and back in 2.6 s. If light travels at 300 000 000 m/s, calculate the distance to the moon.

   If the light takes 2.6 s to go *there and back*, it takes half of this time—1.3 s—to reach the moon.

$$\begin{aligned} d &= v \times t \\ &= 3 \times 10^8\,\mathrm{m/s} \times 1.3\,\mathrm{s} \\ &= 3.9 \times 10^8\,\mathrm{m}, \text{ or } 390\,000\,\mathrm{km}. \end{aligned}$$

Extension problems

6. Other galaxies in space are moving away from us, owing to the expansion of space. In fact, the further away the galaxy, the faster it is moving - this is described by the Hubble constant, $H_0 = 160\,\mathrm{km/s}$ per million-light-years.

   (a) Use the Hubble constant to estimate how fast the Pinwheel Galaxy (M101 / NGC 5457), at 21 million light years distance from the Earth, is moving away from us.

$$\begin{aligned} &\frac{160\,\mathrm{km/s}}{\text{million-light-years}} \times 21\,\mathrm{million{-}light{-}years} \\ &= 3360\,\mathrm{km/s}. \end{aligned}$$

   (b) How much farther away will it be in a year's time?

$$\begin{aligned} &\frac{3360\,\mathrm{km}}{\cancel{\mathrm{s}}} \times 1\,\cancel{\mathrm{year}} \times \frac{365\,\cancel{\mathrm{day}}}{\cancel{\mathrm{year}}} \times \frac{24\,\cancel{\mathrm{h}}}{\cancel{\mathrm{day}}} \times \frac{60\,\cancel{\mathrm{min}}}{\cancel{\mathrm{h}}} \times \frac{60\,\cancel{\mathrm{s}}}{\cancel{\mathrm{min}}} \\ &= 1.06 \times 10^{11}\,\mathrm{km}. \end{aligned}$$

7. Read this passage from *The memoirs of Sherlock Holmes* (the Silver Blaze adventure)

   > "We are going well," said he, looking out the window and glancing at his watch. "Our rate at present is fifty-three and a half miles an hour."
   >
   > "I have not observed the quarter-mile posts," said I.
   >
   > "Nor have I. But the telegraph posts upon this line are sixty yards apart, and the calculation is a simple one."

Repeat Holmes' calculation of the train's speed.

Notice that Holmes has 'glanced' at his watch while watching the telegraph posts—sixty yards apart—appear to go past the window. Can we find a simple way to find the speed of the train in miles per hour if we know the rate at which the telegraph posts go past? We can start by finding out the relation

$$\frac{1\,\mathrm{mile}}{\mathrm{h}} = \frac{1760\,\mathrm{yard}}{3600\,\mathrm{s}},$$

which allows us to work out that the speed at which Holmes is travelling, 53.5 mph, is equal to 26.2 yard/s. This means that the time between two telegraph posts being level with the window is 2.29 s. Holmes is unlikely to be able to measure to better than a second on his wristwatch, and therefore to achieve the accuracy of the speed to the nearest half mile per hour (around 1%) he would need to measure the time for about 100 s. This isn't consistent with a 'glance' at his watch, so there must have been some other way: to be continued...