## 1 Simple measurements using a temperature sensor

1. Making reference to the graph in fig. 1 describe how the resolution of sensor A varies with temperature.

Initially the gradient is steep, giving a high sensitivity which means that the temperature resolution is small. At around 22$^{o}$C the gradient changes making the sensitivity lower and the resolution larger.

2. A student realises that the system for sensor B was not set up correctly during calibration. The voltmeter for sensor B should have read 0.0 mV at 0 $^{o}$C. Why is this a systematic error. If temperatures were measured using a sensor that was set to record 0.0mV at 0$^{o}$C what is the correction necessary for all recorded temperatures?

All readings are incorrect by a fixed amount so this is systematically wrong. Each temperature must be reduced by 7$^{o}$C.

## 2 Trolley down a ramp

1. Explain with calculations how the height h can be used to set the ramp to an angle of 5$^{o}$. Length of ramp = 1.22m

$$\frac{h}{L} = sin\theta \ so \ h = Lsin\theta = 1.22sin5 = 0.106m$$

The end of the ramp needs to be raised by 0.106m

2. If h can be set to the nearest 1mm, what is the precision/uncertainty that can be achieved when setting the ramp to an angle of 5$^{o}$? Give your answer in degrees.

A 1mm precision gives an uncertainty of $\frac{1}{106} \times 100 = 0.94\%$

Therefore the angle is set to a precision of 5$^{o}$ x 0.0094= ±0.05$^{o}$

3. If the ramp were set to the same angle using a protractor estimate what precision could be achieved? Give your answer in degrees.

   Precision= ±1$^{o}$ or 20%

4. The trolley passes through the light gate at 2.32ms$^{-1}$. The mask is 5cm long.
   a. How long does it take for the mask to pass through the light gate.

$$time = \frac{distance}{speed} = \frac{0.05}{2.32} = 21.6ms$$

b. If the timer measures to the nearest 1ms, what is the percentage uncertainty in the measured time?

$$\frac{1}{21.6} \times 100 = 4.64\%$$

c. Since $a = \frac{v^2}{2s}$ what is the percentage uncertainty in the measurement of a?

Since v is squared the uncertainty doubles, 9.3%

**3 Measuring the speed of light**

1. Using Galileo's method estimate the time that might have been measured for a round trip of 2 miles (3200m)

   The measured time will be roughly equal to human reaction time, or it could be argued twice human reaction time. So answers between 0.1s and 0.6s could be acceptable. Median answer =0.35s

2. Use your answer to calculate a minimum value for the speed of light.

$$speed = \frac{distance}{time} = \frac{3200}{0.35} = 9100ms^{-1}$$
$$answer\ is\ approximate\ so\ do\ not\ give\ more\ than\ 2\ sig\ figs.$$

3. Why is your answer a minimum value?

The time measured was all uncertainty. The **actual time must be smaller than the measured time**, which would give a greater speed.

4. Michelson gave his value of the speed of light as 299910 ± 50 kms-1.

   a. According to Michelson what is the allowed range of values for the speed of light?

   299960 to 299860 $kms^{-1}$

   b. Compare this range to the accepted value for the speed of light. How might this imply that:

      i. Michelson had a systematic error

The current accepted value of c is lower than the minimum found by Michelson. So his results might all have come out too high due to a systematic error.

ii. Michelson had under estimated his uncertainty.

If there is no systematic error then the uncertainty must be larger than he estimated so that the range includes the correct value of c.

5. Why was it necessary for the first time to correct the speed of light in air once Michelson had published.

   Previous attempts at measurement had been insufficiently accurate to detect the difference of light speed in air compared to in vacuo.