

**Advanced Subsidiary GCE
PHYSICS B (ADVANCING PHYSICS)**

G492

Unit G492: Understanding Processes
Advance Notice

Specimen

May be opened and given to candidates upon receipt.



INSTRUCTIONS TO CANDIDATES

- Take this information away and read it carefully. Spend some time looking up any technical terms or phrases you do not understand. You are not required to research further the topic described.
- For the examination on you will be given a fresh copy of this Advance Notice, together with a question paper. You will not be able to take your original copy into the examination with you.
- The value of standard physical constants will be given in the Advancing Physics Data, Formulae and Relationships booklet. Any additional data required are given in the appropriate question.

INFORMATION FOR CANDIDATES

- Questions in Section C of Paper G492, Understanding Processes, will refer to material in this Advance Notice.
- Section C will be worth about 40 marks.
- Sections A and B will not be based on the material in the Advance Notice.

This document consists of **5** printed pages and **3** blank pages.

1. Uncertainties and errors in measurements in science

Random uncertainties are not mistakes, but are present in any measurement. They result in a scatter of readings about a mean value. They can be positive or negative. They result from the inability of the experimenter to repeat actions precisely.

Systematic errors may also be present in measurements. These result in all the readings taken being faulty in one direction. They can be caused by the apparatus or poor experimental technique.

2. The speed of light: from measurement to definition

Measurement of the velocity of light c was important in determining the nature of light.

Rømer and Huygens: observations of moons of Jupiter

The speed of light was first estimated from astronomical observations, when Rømer noticed up to 11 minute delays and advances in the times of eclipse of planets of Jupiter. At the time, it was no mean feat to have clocks that could measure differences in time of a few minutes over a six-month period. Using the best guess available for the diameter of the Earth's orbit, in 1690 Huygens arrived at a figure of about $200\,000\text{ km s}^{-1}$ for the speed of light.

Fizeau, Foucault and Michelson: making measurements on Earth

It was not until 1849 that ways were found to make terrestrial measurements. First was Fizeau, who chopped a beam of light into pulses by sending it through the teeth of a rotating 720 tooth wheel. The pulses were sent to a mirror some kilometres away, and returned to the spinning toothed wheel, travelling a total of 17.2 km. Fizeau found that when the wheel rotated at 12.6 revolutions s^{-1} , each returning pulse of light was just blocked by the next tooth having moved into its path. This gave him a value of $313\,300\text{ km s}^{-1}$ for the speed of light.

A year later, in 1850, Foucault found a way to do the experiment using a much shorter light path of 40 m. His idea was to reflect light from a rapidly spinning mirror, send it out to a fixed mirror and back to the rotating mirror. In the time taken for the light to go out and back, the spinning mirror turned through a small angle, so that the returning light was deflected through twice that angle. Because of the short light path, Foucault was able to send the light through water as well as air, and to show that light definitely travelled slower in water. This was what the wave theory of light had predicted, as opposed to the particle theory, which suggested the opposite.

The rotating mirror method was much improved and developed over the next half century, culminating in two sets of measurements by Michelson and colleagues. These used rotating mirrors, but the mirrors were made 8-sided so that Michelson could look for the speed of rotation at which the light reflected out by one face of the mirror was reflected by the next face when it came back. Thus he had only to detect zero deflection of the image, which can be done with less uncertainty than measuring a small deflection, as Foucault had to do.

The first set of measurements were made over an 18 km light path, between Mount Wilson and Mount San Antonio in California, determined to within a claimed uncertainty of $\pm 3\text{ mm}$, giving a value of $299\,796 \pm 4\text{ km s}^{-1}$

Speed in air – speed in a vacuum

The uncertainty in the measurement of only a few km s^{-1} was now small enough that the refractive index of the air had to be taken into account. In the mountain-top conditions used by Michelson, the light travelled 67 km s^{-1} slower in air than it would have in a vacuum. Atmospheric conditions affect the speed of light in air and vary from day to day and along the light path, so Michelson could not be very sure of the correction to make to allow for the speed in air. Together with Pease and Pearson, he set about removing this source of uncertainty. The idea was simply to do the same experiment in a vacuum, so that no correction was needed.

In 1932, a year after Michelson's death, results were published of the average of 3000 measurements made in a mile-long evacuated tube buried underground near the Californian sea-shore. Using multiple reflections up and down the pipe the total light path was about 16 km.

The result was $299\,774\text{ km s}^{-1}$, which is 22 km s^{-1} slower than Michelson's mountain-top measurement. The claimed uncertainty, because of the large number of measurements, was better than before. The new low value was internationally adopted, but with an increased uncertainty estimate. Thus for the 1930s and 1940s the speed of light was officially decided to be $c = 299\,774 \pm 11\text{ km s}^{-1}$.

War-time radar and microwave standing waves

In World War 2, radar was developed to detect enemy aircraft. Measuring the range of an aircraft involves measuring the time delay of a reflected radar pulse, and using the agreed value of the speed of light. It slowly became clear that there was a discrepancy. Objects at a known distance were regularly measured by radar to be a bit closer than they were known to be. The discrepancy was not large enough to spoil radar ranging of aircraft – about 7 m in 100 km. However, after the war, this led physicists to look again at measuring the speed of light, using the advances in microwave generation and frequency measurement made partly as a result of the war effort. A series of measurements, using interference in microwaves, converged on a value higher than the official $299\,774 \pm 11\text{ km s}^{-1}$. One of the best, made by Froome in 1958, gave $c = 299\,792.5 \pm 0.1\text{ km s}^{-1}$.

Adopting a new value, then choosing the speed of light by definition

As lasers became available, and became more and more stable, it became possible to measure both their frequency and wavelength with high precision. By 1973 the uncertainty in the speed of light had been reduced by a factor of 100, to only $\pm 1\text{ m s}^{-1}$. In 1973 the International Committee of Weights and Measures recommended the value

$$c = 299\,792\,458 \pm 1\text{ m s}^{-1}.$$

It soon became clear that the limit to uncertainty was the measurement of distance. The old definition of the metre as the distance between two marks on a metal bar was subject to greater uncertainty than the wavelength measurements. As a result, in 1984, by international agreement, the physics community took the radical step of abandoning the historic definition of the metre. Instead, the speed of light was chosen to be

$$c = 299\,792\,458\text{ m s}^{-1}\text{ exactly.}$$

Since then, distances have been measured in terms of the time taken for light to travel them.

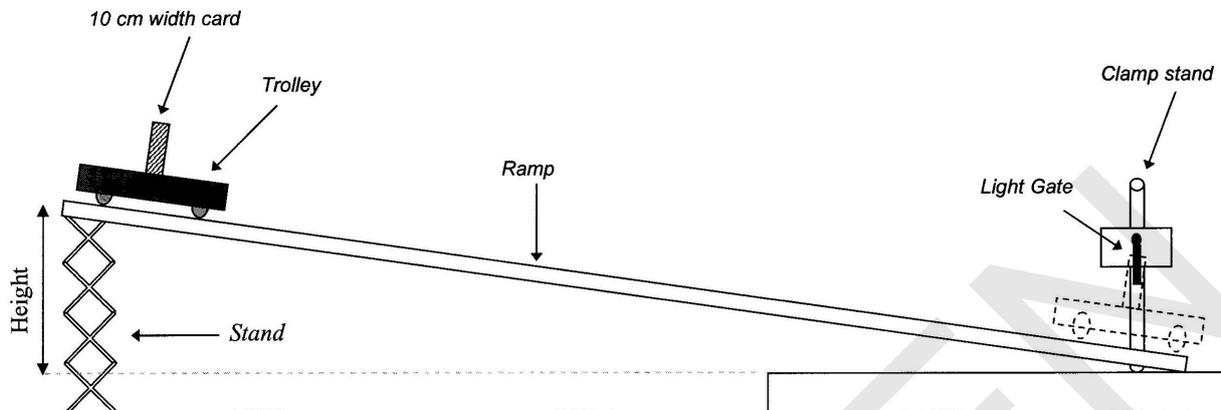
The following table shows the results obtained by some experimenters between 1875 and 1951.

year	experimenter	observed velocity/ km s^{-1}
1875	Cornu	$299\,990 \pm 200$
1880	Michelson	$299\,910 \pm 150$
1883	Michelson	$299\,850 \pm 60$
1906	Rosa-Dorsey	$299\,784 \pm 10$
1928	Middelstaedt	$299\,778 \pm 10$
1932	Michelson with others	$299\,774 \pm 4$
1941	Anderson	$299\,776 \pm 6$
1951	Bergstrand	$299\,793.1 \pm 0.3$

[Turn Over

3. Fiona and Tom's trolley experiment

This set of data is about the motion of a trolley down a ramp as shown in the diagram below. The experiment was carried out by two AS students, Fiona and Tom.



mass of trolley m	0.992 kg
"mask" width w	10.0 cm
runway length s	1.20 m

One end of the runway was raised to a height h . The trolley had a mass of 0.992 kg and had a card 'mask' of width 10.0 cm mounted on it. The time t taken for the card mask to pass through a light gate at the bottom of the 1.20 m long ramp was measured.

height h / cm	time t / s
4.0	0.164
6.0	0.113
8.0	0.091
10.0	0.078
12.0	0.071
16.0	0.061
20.0	0.053

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