RADLEY

2023 Scholarship Examination Paper

PHYSICS

22 February – 23 February 2023

Time allowed – 30 minutes

PLEASE WRITE IN BLACK INK

Calculators are not to be used

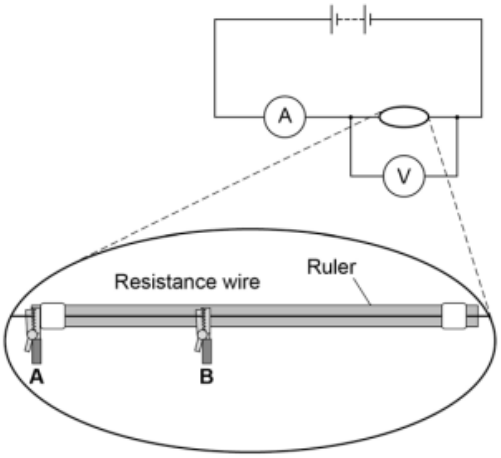
Total marks available = 33

Instructions:

- Most of the marks are for showing clear thinking.
- Your final answers are less important than demonstrating a logical and systematic approach.
- Use bullet points
- Show your working out at all stages. State any assumptions that you make.
- Where you can, use powers of ten to show very big or very small numbers. For example, "1,000,000" can be written: 1.0×10^6

Question 1

Tell me as much as you can about what you can see in this diagram:



(5 marks)

Question 2

When doing an estimation, as is often the case when solving a tough problem in life, it is often a good idea to divide and conquer.

Make sure you show your reasoning carefully in this question:

How many tennis balls does Radley College buy every year?

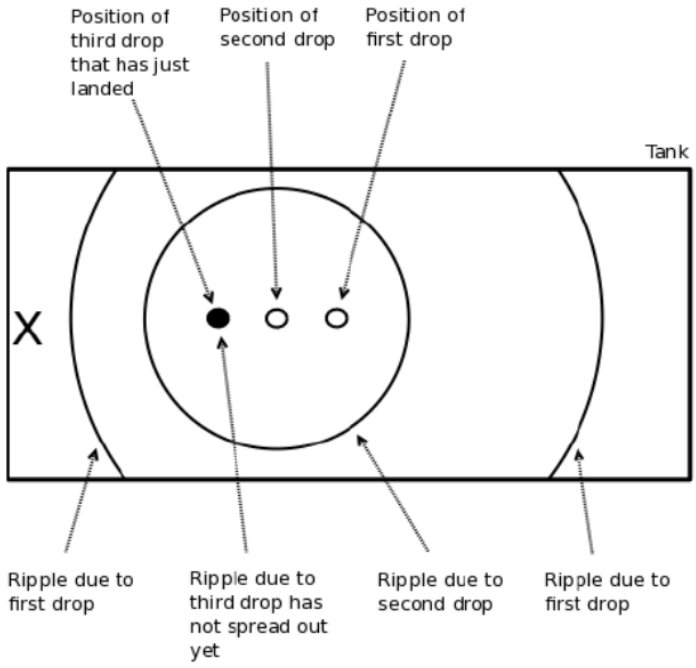
(5 marks)

Question 3

A group of students investigates how the sound from a moving car appears to change its frequency (pitch) compared to when the car is stationary.

They use a model where water drops from a source moving at a constant speed cause ripples to spread out on the surface of a tank of still water.

In the model the ripples that spread out represent the sound waves from the moving car. The diagram shows the position where three drops landed and the position of the ripples due to the first two drops. The third drop has only just landed and so the ripple has not spread out yet.



The ripples travel at speed v = 9.0 cm/s The source moves at speed c = 4.0 cm/s The drops occur every half second

(a) State the frequency at which the drops are released (how many per second)
(1 mark)

(b) Show that the time interval between successive ripples arriving at point X is around 0.28 s
(3 marks)

(c) State the frequency of the waves arriving at point X
(1 mark)

When a car is stationary the horn has a frequency of 300 Hz.

When the car moves at 5.00 m/s towards an observer the horn appears to have a slightly higher frequency.

(d) By calculating the time period of the sound and referring to the model described previously, estimate the frequency of the horn that the observer hears. (speed of sound = 340 m/s)

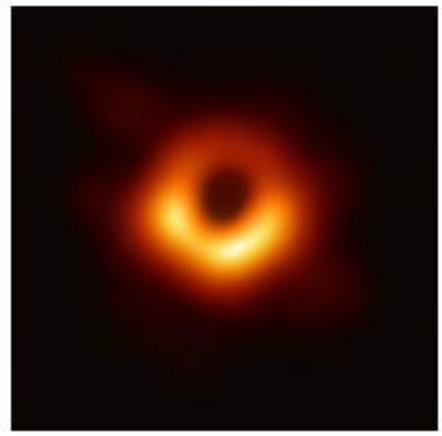
(4 marks)

Question 4

In April 2019 The Event Horizon Telescope (EHT) collaboration published the first direct image (shown below) of a supermassive black hole named M87* (read as M87 star) at the centre of a nearby galaxy named M87.

A black hole is a massive astronomical object so dense that even light cannot escape its enormous gravitational field.

The radius of the event horizon of a black hole is the distance from the centre at which light cannot escape and can be thought of as the "size" of the black hole.



The photograph published by the Event Horizon Telescope collaboration shows a dark region of shadow about **2.5 times** the diameter of the event horizon surrounded by clouds of brightly glowing gas.

The following information is required:

o Mass of the Sun = 2×10^{30} kg

o Distance from Sun to Earth = 1 AU

o Distance from Sun to Pluto = 40 AU

o 1 AU = 1.5×10^{11} m

o Radius of Earth = 6400 km

o Mass of M87* = 6.5×10^{9} solar masses

o Distance to M87* = 55 million light years

o Gravitational constant, G = 6.67×10^{-11} N m^2/kg^2

o Speed of light, c = 3×10^{8} m/s

Notes: AU is a measurement of distance called an Astronomical Unit.

A light year is a measurement of distance equal to the distance travelled by light in one (Earth) year.

a) Before direct imaging was possible, suggest how astronomers could have identified the location of black holes. (1 mark)

b) After the release of the image of M87*, one news article claimed "The black hole M87* is as big as our entire Solar System"
The radius of the event horizon of a black hole is given by the equation for the Schwarzschild radius

$$r_S = \frac{2GM}{c^2}$$

where *M* is the mass of the black hole
Use the information given to compare the radius of the event horizon of M87* and the radius of the solar system and hence comment on the validity of the claim.
(4 marks)

c) Show that the distance to M87* is about 5×10^{23} m

(2 marks)

d)

Astronomers observing a far away object calculate the angular size of an object.

The angular size is the angle (ϕ) from one edge of the object to the other as observed from Earth.

$$\tan\phi \approx {}^{d}/_{D}$$

Using the photograph, show that the angular size of the image of M87* (including the glowing gas clouds) is about 30×10^{-9} degrees

[3 marks]

e) The angular resolution of a telescope is the smallest angle (R) between two objects such that they can been seen as separate.

The angular resolution (R) is given by

$R \approx 60 \times \lambda / D$ where λ i
is the wavelength of the radiation being detected, D is the diameter of the telescope aperture and R is measured in degrees. D and lambda are in the same units.

The Event Horizon Telescope uses a consortium of smaller telescopes from across the globe all connected together so that the effective diameter of the EHT is approximately the diameter of the earth.

Given that the EHT observes radiation at a frequency of 230 GHz (1 GHz = 1 x 10^9 Hz), show that the EHT has a good enough resolution to produce the image of M87*.

(4 marks)