Physics Challenge 2022

Mark-scheme

Note to teachers:

The paper is designed to be challenging. Questions based on unfamiliar physics require students to analyse the information given. The mathematical content may involve unfamiliar units. Students are asked to estimate reasonable values and evaluate or justify arguments.

The questions are designed to be accessible to all students independent of exam board or syllabus. If a question is deemed to be unfair due to the particular syllabus studied, teachers are encouraged to use the opportunity to comment on the paper. All comments are taken seriously and used to refine future papers.

Preamble:

Please award marks as indicated below.

Equivalent valid reasoning should gain equal credit to the solutions presented here.

Error carried forward marks may be awarded where an incorrect answer is used as part of the data needed for a subsequent question, providing that the resulting answer is not plainly ridiculous.

If incorrect units are used more than once then a maximum of **one** mark should be deducted from the total.

If an inappropriate number of significant figures is given more than once in final answers then a maximum of **one** mark should be deducted from the total.

Section A – Multiple Choice Questions [1 mark each]

1	2	3	4	5	6	7	8	9	10
D	B	B	D	A	C	C	A	C	B

Section B – Short Answer Questions

Marks for these two questions should be awarded for a clear explanation of the underlying physical principals using correct scientific terminology at a level appropriate for students of this age.

Answers that are incomplete, contain errors in physics or use terminology incorrectly cannot be awarded full credit.

Markers are **encouraged to be generous** and award credit where possible.

Question 11:

For **Question 11** the following should be used: [5 marks]

Award 0 marks:	No valid attempt made to answer question
Award 1 mark:	Single valid point presented but other-wise incorrect or incomplete
Award 2 marks:	Partially correct answer but major error(s) or omission(s) in reasoning
Award 3 marks:	Mostly correct answer, only minor error(s) or omission(s) in reasoning
Award 4 marks:	Essentially correct answer, no errors or omissions of reasoning but answer is not clear on first reading, is confused or uses terminology incorrectly
Award 5 marks:	Completely correct answer, no errors, omissions of reasoning or incorrect use of terminology, clear on first reading

Any valid explanation should be awarded credit

Example solutions might include, but are not limited to:

- A solar eclipse occurs when the Moon passes in front of the Sun, casting a shadow on the Earth
- The Moon is smaller than the Earth but close, so the shadow of the Moon (umbra and penumbra) cast on the Earth only covers a relatively small area of the planet's surface – typically the (umbra) shadow is a few 100 km wide. An observer needs to be pretty much along the line of sight of Moon and Sun in order for the Moon to block the Sun.
- The Moon and Sun are a similar apparent size in the sky. The time for which the Moon blocks (part) of the Sun is relatively short, typically just a few hours. A total solar eclipse only lasts a few minutes.
- During this time the shadow of the Moon on earth moves across the Earth's surface. The narrow track of the Moon's shadow over several hours is a (very) small part of the Earth's surface
- A lunar eclipse occurs at the full moon. The Earth is between the Sun and the Moon so that the Earth casts a shadow on the Moon
- The full moon, and therefore a lunar eclipse, can be observed from the half of the planet that is facing away from the Sun and towards the Moon
- A lunar eclipse can also last several hours with a total lunar eclipse lasting between 30 minutes and an hour. During this time the Earth rotates meaning that areas that do not observe the start of the eclipse may still observe the end of the eclipse. Therefore, the area of the planet from which a lunar eclipse can be observed is (slightly) greater than the area of one hemisphere – just over half the Earth's surface.

Question 12:

A voltmeter should not affect the (current in) the circuit [1 mark]

Because the voltmeter is used in parallel (with the bulb and/or power supply) there is a potential difference across the voltmeter. No current should take the path through the voltmeter meaning that it must have an infinite resistance [1 mark]

a) The current measured by the ammeter would increase because current flows through the voltmeter as well as through the bulb [1 mark]
b) The potential difference across the bulb measured by the voltmeter would not change because the bulb and voltmeter are in parallel with the power supply (as ammeter has zero resistance) [1 mark]
c) Calculated resistance would be too low because the current used in the equation is greater than the current through the bulb itself [1 mark]

For answers (a) to (c) there must be some sort of explanation (anywhere in the question) to gain credit

Section C – Longer Answer Questions

Question 13

(a) t_{average} = 2.45 s v = 1.2 / 2.45 v = 0.49 m/s [1]

(b) $v_{\text{average}} = \frac{1}{2}(u + v)$ u = 0 $v_{\text{average}} = \frac{1}{2}v$ $v_{\text{final}} = 2 \times v_{\text{average}}$ owtte [2]

(c) $a = (2 \times v_{\text{average}} - 0) / t$ a = 0.40 m/s^2 [1]

(d) realisation that $a \propto h$ means $a/h = constant$ process [1]

h = 5 cm a = 0.400 m/s^2 a / h = 8.0 (s^{-2}) (no units required for credit)

h = 9 cm a = 0.720 m/s^2 a / h = 8.0

h = 13 cm a = 1.03 m/s^2 a / h = 7.9 calculations [1]

$a/h = constant$ therefore $a \propto h$ is verified conclusion [1]

(e) realisation that $g = \left(a/h\right) \times L$

h =5 cm g = 9.60 m/s^2

h = 9 cm g = 9.60 m/s^2

h = 13 cm g = 9.51 m/s^2 calculations [1]

Therefore, the results give g = 9.57 m/s^2 accept g = 9.6 m/s^2 conclusion [1]

This section can only gain both marks if all the data is used i.e. not just a single calculation

(f) Difference between calculated value of g = 9.6 m/s^2 and value given in data sheet of g = 10 m/s^2 is 0.4 m/s^2 or approximately 4 % [1]

0.5 cm as a percentage of the height is between 10 % and 4 % [1]

Range of timing values is 2 % for two sets of timings and 0.5 % for the third set [1]

Any valid conclusion: "The is more justified as the uncertainty in the ramp height is the same as, or greater, than the uncertainty in the value of g" **or** "both the uncertainty in the timing and the ramp height are a few percent and both could have contributed to the lack of accuracy, the student's and the teacher's conclusions are both justified" or any other reasonable conclusion based on correct analysis of the times and dimensions given. [1]

Question 14

(a) light ray reflected twice internally and emerging parallel (by eye) to the incident ray [1]

(b) The reflected ray from a prism arrangement is always parallel to the incident ray and will reflect back towards the source [1]

A plane mirror would not necessarily reflect light back towards the source and so could not be detected on earth. [1]

(c) Power = energy / time Power = 115×10^{-3} / $100 \times 10^{-12} = 1.15 \times 10^{9} \approx 1$ GW [1]

(d) $f = {}^{c}/_{\lambda}$ $f = 3 \times 10^{8}$ / 532×10^{-9} $f = 5.6(4) \times 10^{14}$ Hz [1]

(e) Number photons = pulse energy / photon energy

Photon energy = $6.63 \times 10^{-34} \times 5.64 \times 10^{14}$ Photon energy $= 3.74 \times 10^{-19}$ J [1]

Number of photons $= 115 \times 10^{-3}$ / 3.74×10^{-19} Number of photons $= 3.1 \times 10^{17}$ [1]

(f) The time between a pulse being sent and subsequently returning needs to be measured. If a continuous beam was used it would not be possible to know when the received photons had been sent, so no timing information could be recorded. [1]

(g) $\tan(0.001/2) = r/\ 384\ 000$ $r = 3.35$ km diameter $= 6.7$ km ≈ 7 km [1]

Allow use of $\tan(0.001) = d \div 384\ 000$ diameter $= 6.7$ km

(h) Number of photons = (Area reflector / Area circle) x number of photons in pulse [1]

Number of photons incident on reflector = $(0.46^{2} \div (\pi\ x\ 3350)^{2}) \times 3.1 \times 10^{17} = 1.8 \times 10^{9}$ [1]

(i) The situation is exactly the same as (h) with the mirror effectively a point source

Number of photons received by telescope $= (\pi \times 1.75^{2} \div (\pi \times 3350)^{2}) \times 1.8 \times 10^{9}$

$= 490 \approx 500$ [1]

(j) Time for light to travel 15 mm = $0.015 \div 3.0 \times 10^{8} = 5 \times 10^{-11}$ seconds [1]

Time for light to travel 12 km in vacuum = 12 000 / $3.0 \times 10^{8} = 4.0 \times 10^{-5}$ seconds

Time for light to travel 12 km through air = 12 000 / $(3.0 \times 10^{8} \div 1.0003)$ = 4.0012×10^{-5} seconds

Difference in calculated times to travel through atmosphere = 1.2×10^{-8} seconds [1]

The time difference caused by the atmosphere is much greater than the level of precision required to measure distances to 15 mm and so it must be taken into account [1]

(k) 3.8 cm / year for 10 000 years is a change of the radius of the orbit of the Moon of 380 m [1]

There would be no noticeable difference for a person observing from Earth [1]