Please check the examination details below before entering your candidate information

Candidate surname: Matheson

Other names: Lewis

Centre Number: 8 4 5 9 0

Candidate Number: 4 5 2 3

Pearson Edexcel Level 3 GCE

Friday 9 June 2023

Morning (Time: 1 hour 45 minutes)

Paper reference **9PH0/02**

Physics

Advanced

PAPER 2: Advanced Physics II

ALevelPhysicsOnline.com/edexcel-advanced-physics-2

You must have:
Scientific calculator, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- In the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- The list of data, formulae and relationships is printed at the end of this booklet.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations, including units where appropriate.

Turn over ▶

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N:1/1/1/E2/

P 7 1 9 1 6 A 0 1 3 2

Pearson

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 A sphere of radius r is made from material of density ρ_M. The sphere is fully immersed in a liquid of density ρ_L.

Which of the following expressions gives the upthrust on the sphere?

☐ **A** $4\pi r^2 \rho_M$

☐ **B** $\frac{4}{3}\pi r^3 \rho_M g$

☒ **C** $\frac{4}{3}\pi r^3 \rho_L g$

☐ **D** $4\pi r^2 \rho_L g$

upthrust = weight of fluid displaced

$\rho_L = \frac{m_L}{V}$ $m_L = \rho_L V$

$W = m_L g = \rho_L V g = \rho_L \frac{4}{3}\pi r^3 g$

(Total for Question 1 = 1 mark)

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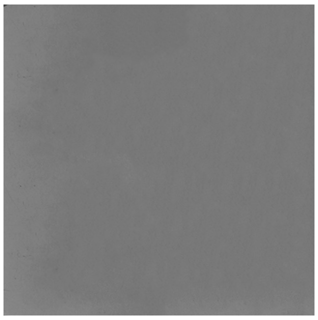
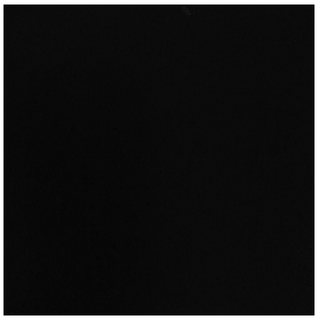
P 7 1 9 1 6 A 0 2 3 2

2 A source of light is viewed through a polarising filter, as shown in photograph 1.

The filter is rotated through an angle and then viewed, as shown in photograph 2.



Photograph 1



Photograph 2

Which row of the table shows whether the light emitted by the source is polarised or unpolarised, and the angle of rotation of the filter?

	Light emitted by source	**Angle of rotation / radians**
A	polarised	$\frac{\pi}{2}$
B	polarised	π
C	unpolarised	$\frac{\pi}{2}$
D	unpolarised	π

(Total for Question 2 = 1 mark)

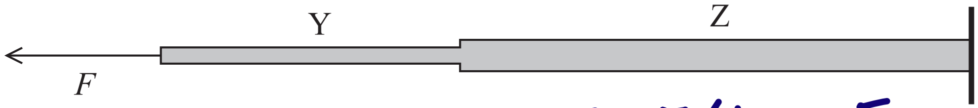
3 Two stars, P and Q, are observed from Earth. The intensity of radiation from P is less than that from Q. The parallax angle for P is greater than that for Q.

Which row of the table is correct?

	Distance from Earth	**Comparison of luminosities**
A	P is closer than Q	luminosity of P is greater than Q
B	P is closer than Q	luminosity of P is less than Q
C	P is further away than Q	luminosity of P is greater than Q
D	P is further away than Q	luminosity of P is less than Q

(Total for Question 3 = 1 mark)

4 A wire Y of cross-sectional area A and length l is joined to a second wire Z of cross-sectional area $2A$ and length $2l$ as shown. Wire Z is fixed at one end and a force F is applied to the other end of wire Y.



The wires are made of the same material.

Wire Y extends by a distance x.

Which of the following is the extension of wire Z?

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta x/x} = \frac{Fx}{\Delta x A}$$

$$\Delta x = \frac{Fx}{EA} = \frac{FL}{EA}$$

☐ **A** $4x$

☐ **B** $2x$

☒ ✓ **C** x

☐ **D** $\frac{x}{2}$

Y: $\Delta x_Y = \frac{FL}{EA}$ Z: $\Delta x_Z = \frac{F2L}{E2A} = \frac{FL}{EA} = \Delta x_Y$

(Total for Question 4 = 1 mark)

5 A raindrop is falling through the air with an increasing velocity. The forces on the raindrop are weight W, upthrust U and viscous drag F.

∴ Resultant force down

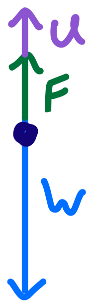
Which of the following shows the relationship between these forces?

☐ **A** $F + U = W$

☐ **B** $F = W + U$

☐ **C** $F + W < U$

☒ ✓ **D** $F + U < W$

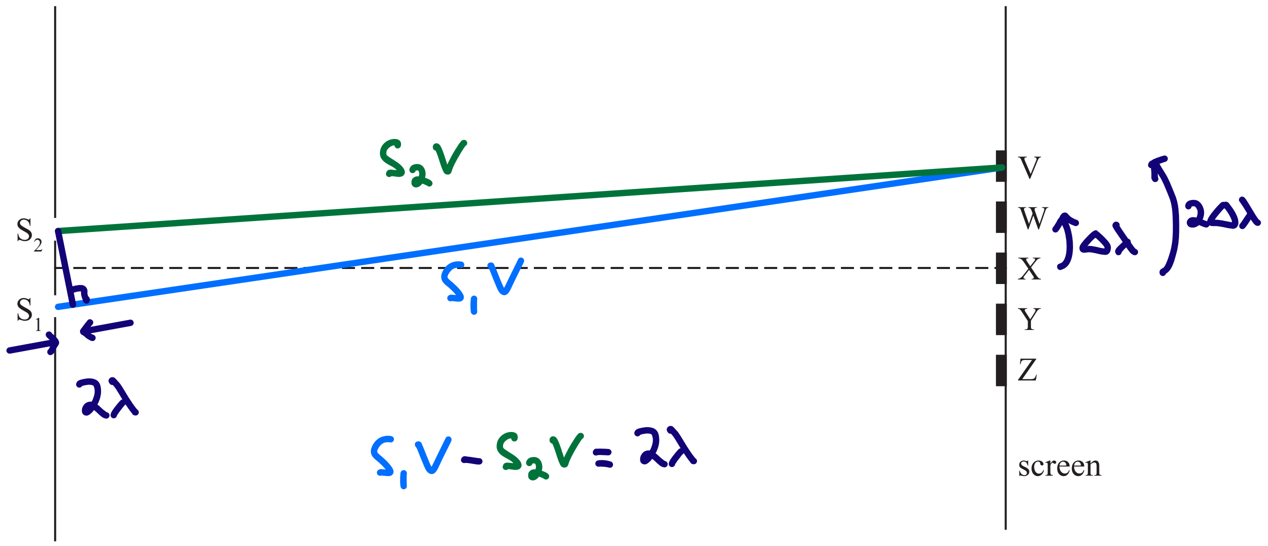


Resultant force = $W - F - U$

∴ $W > F + U$

(Total for Question 5 = 1 mark)

6 Monochromatic light of wavelength λ is incident normally on two slits, S_1 and S_2, producing an interference pattern on a screen as shown. V, W, X, Y and Z represent positions of adjacent maxima.



The distance from S_1 to X is represented as S_1X.

Which of the following expressions is equal to 2λ?

☐ **A** $S_1Z - S_2X$

☒ **B** $S_1V - S_2V$

☐ **C** $S_1Y - S_2Y$

☐ **D** $S_1W - S_2Y$

(Total for Question 6 = 1 mark)

7 Carbon-14 is a radioactive isotope with a decay constant of 1.2×10^{-4} year^{-1}.

The fossil of a plant contains 24% of the amount of carbon-14 that would have been present when the plant was alive.

Which of the following expressions gives the age of the fossil in years?

- ☐ **A** $1.2 \times 10^{-4} \times \ln \dfrac{1}{0.24}$
- ☐ **B** $1.2 \times 10^{-4} \times \ln \dfrac{0.76}{0.24}$
- ☒ ✓ **C** $\dfrac{1}{1.2 \times 10^{-4}} \times \ln \dfrac{1}{0.24}$
- ☐ **D** $\dfrac{1}{1.2 \times 10^{-4}} \times \ln \dfrac{0.76}{0.24}$

$m = m_0 e^{-\lambda t}$

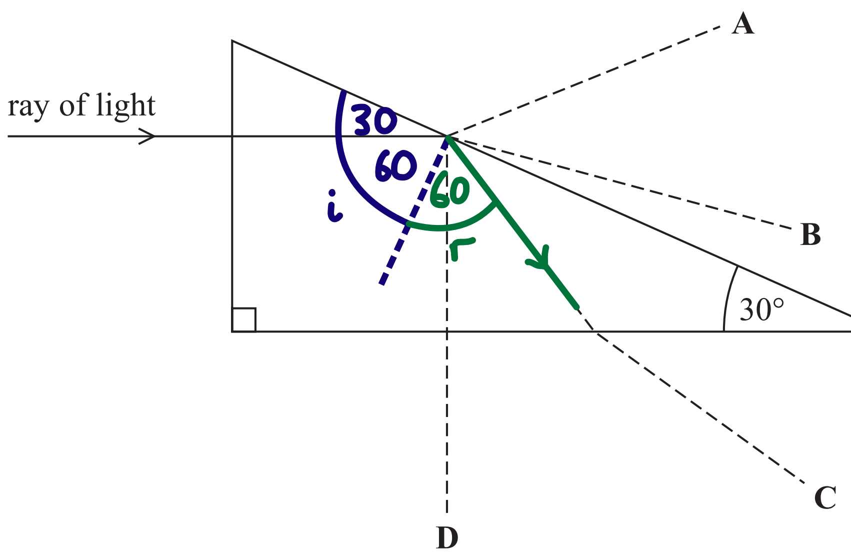
$\dfrac{m}{m_0} = e^{-\lambda t}$ 24%

$\ln 0.24 = -\lambda t$

$\ln \dfrac{1}{0.24} = \lambda t \qquad t = \dfrac{1}{\lambda} \ln \dfrac{1}{0.24}$

(Total for Question 7 = 1 mark)

8 A ray of light is directed towards a prism as shown.
The prism is made from a material with refractive index 1.5



Which of the dashed lines best shows the subsequent path of this ray of light?

- ☐ **A**
- ☐ **B**
- ☒ ✓ **C**
- ☐ **D**

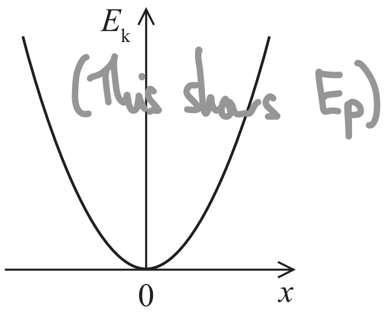
$\sin C = \dfrac{1}{n} \qquad C = \sin^{-1}\left(\dfrac{1}{1.5}\right) = 41.8°$

Angle of incidence > 41.8° ∴ TIR

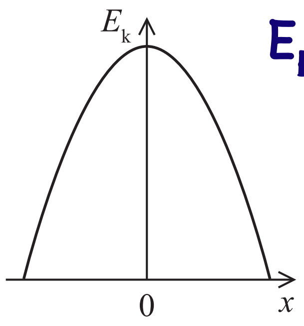
(Total for Question 8 = 1 mark)

9 An object oscillates with simple harmonic motion. The object has kinetic energy E_k and displacement x.

Which of the following graphs shows the variation of E_k with x for the object?

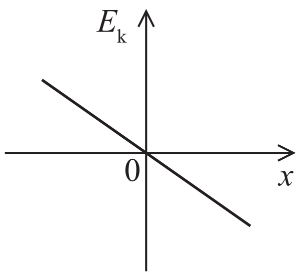


☐ **A**

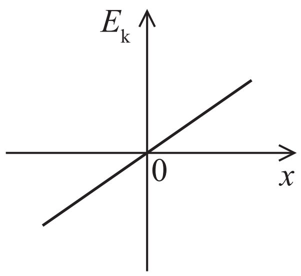


☒ **B**

$E_{k\,max}$ at $x = 0$



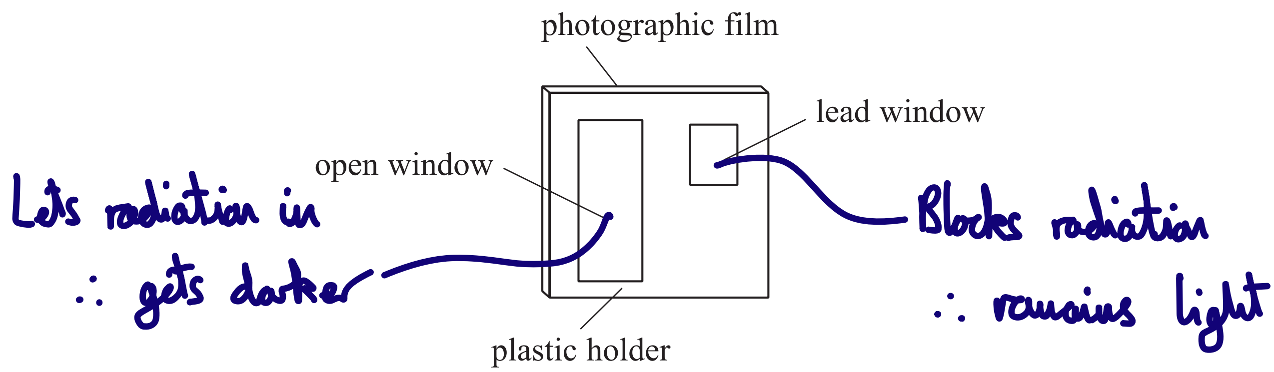
☐ **C**



☐ **D**

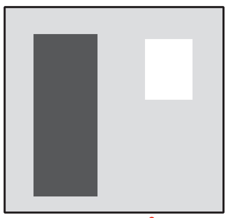
(Total for Question 9 = 1 mark)

10 A radioactivity monitoring badge is worn by people who might be exposed to radiation. The badge is made from photographic film wrapped in thin paper and then held in a plastic holder that has an open window and a lead window, as shown.

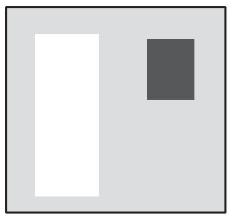


The film gets darker when exposed to ionising radiation.

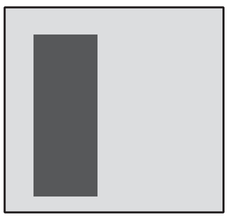
Which of the following represents the film after the badge is exposed to beta radiation?



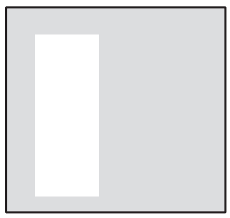
☒ **A**



☐ **B**



☐ **C**



☐ **D**

(Total for Question 10 = 1 mark)

11 The photograph shows a stringed instrument called a cello being played with a bow.

(Source: © Vadim Ponomarenko/Alamy Stock Photo)

A standing wave forms on a cello string when the bow moves across the string.

Deduce whether a thicker string will produce a note of higher or lower frequency compared with a thinner string.

Assume each string is the same length and at the same tension.

Thick string has a greater mass per unit length, μ. ✓

$f = \frac{1}{\lambda}\sqrt{\frac{T}{\mu}}$, λ and T constant $\therefore f \propto \frac{1}{\sqrt{\mu}}$ ✓✓

As μ is greater, f is lower. ✓

(Total for Question 11 = 4 marks)

12 A student placed a metal block of mass 220 g in boiling water at 100 °C for several minutes.

The student then transferred the metal block into 300 g of water at 19 °C inside a glass container of mass 50 g. The final temperature of the water was 23 °C.

The table shows specific heat capacity values for copper and tin.

Metal	copper	tin
Specific heat capacity / J kg^{-1} K^{-1}	390	230

Deduce whether the metal block was made from copper or tin.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific heat capacity of glass = 840 J kg^{-1} K^{-1}

Energy lost by metal = Energy gained by water + glass ✓

$\Delta E = m_m c_m \Delta\theta_m$ ✓ $= m_w c_w \Delta\theta_w + m_g c_g \Delta\theta_g$

$$c_m = \frac{0.300 \times 4200 \times (23-19) + 0.050 \times 840 \times (23-19)}{0.220 \times (100-23)}$$ ✓

$c_m = 307.4 \text{ J kg}^{-1} \text{ K}^{-1}$ ✓

Metal must be copper, as some energy is also transferred to the surroundings ∴ calculated value of c lower than the true value. ✓

(Total for Question 12 = 5 marks)

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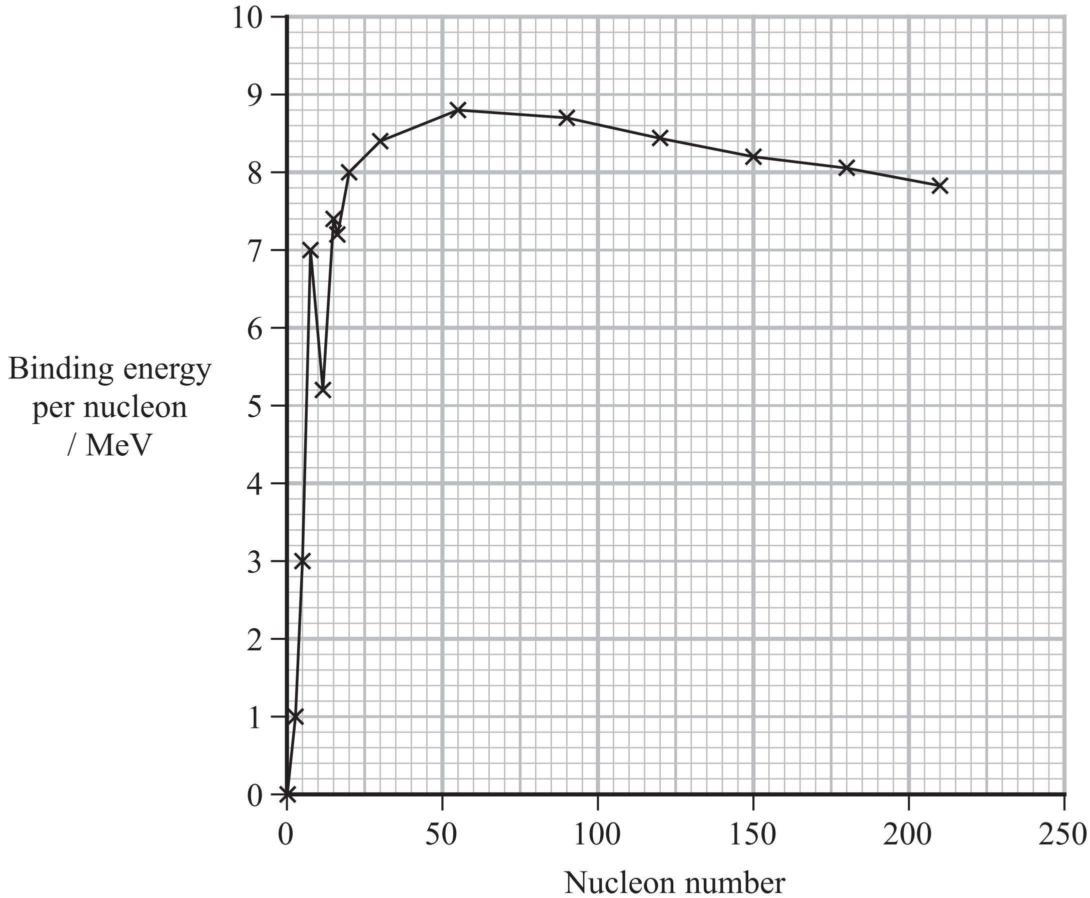
13 A fusion research centre was opened in Rotherham in 2021. The centre has a device which tests materials in the extreme conditions found inside a fusion reactor.

(a) Describe the extreme conditions inside a fusion reactor.

(3)

A plasma ✓ at a very high temperature ✓ in a high magnetic flux density. ✓

(b) The graph shows how the binding energy per nucleon varies with nucleon number for a range of nuclides.



Explain why the fusion of nuclei can produce large amounts of energy. Your answer should refer to information from the graph.

(3)

Smaller nuclei fuse to form larger nuclei. ✓ The binding energy per nucleon increases, releasing energy. ✓

E.g. From nucleon number of 5 (≈ 3 MeV per nucleon) to a nucleon number of 10 (≈ 6 MeV per nucleon). ✓

(Total for Question 13 = 6 marks)

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14 The fuel used in a camping stove is butane, which is stored in a canister as shown.

Some of the butane in the canister is in a liquid state, and some is a gas.

(a) When the stove uses the butane gas, some of the liquid butane evaporates.

Explain why the temperature of the canister decreases when the stove is used.

(3)

The faster molecules of butane have enough energy to escape the liquid ✓ ∴ the average kinetic energy of the remaining molecules decreases ✓ ∴ the temperature of the liquid decreases. ✓

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(b) The pressure inside the canister is 220 kPa and the temperature of the gas is 21 °C.

(i) The canister is in the shape of a cylinder of length 0.23 m and radius 0.11 m.

Calculate the number of molecules of butane gas in the canister.

Assume the volume of liquid butane inside the canister is negligible.

(4)

$pV = NkT$ ✓ $V = \pi r^2 h$ ✓

$$N = \frac{p \pi r^2 h}{kT} = \frac{220\times10^3 \times \pi \times 0.11^2 \times 0.23}{1.38\times10^{-23} \times (273+21)}$$ ✓

$= 4.74\times10^{23}$

Number of molecules of butane gas = 4.7×10^{23} ✓

(ii) Calculate the r.m.s. speed of the molecules of butane gas.

mass of butane molecule = 9.6×10^{-26} kg

(2)

$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ ✓

$$c = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\times1.38\times10^{-23}\times 294}{9.6\times10^{-26}}} = 356 \text{ ms}^{-1}$$

r.m.s. speed = 360 ms^{-1} ✓

(Total for Question 14 = 9 marks)

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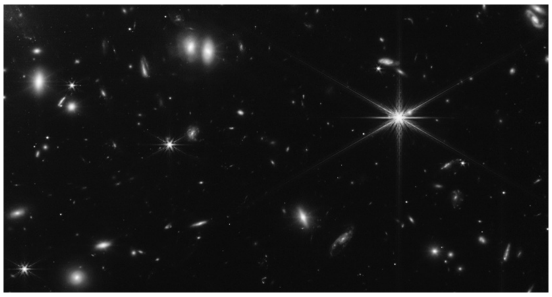
15 The photograph below was taken by the James Webb Space Telescope (JWST) and shows a group of galaxies that formed shortly after the big bang, about 13×10^9 years ago.



(Source: © NASA, ESA, CSA, STScI)

(a) (i) Derive the equation $T = 1/H_0$ where T is the age of the universe.

(1)

$v = H_0 d$ $\quad v = \frac{d}{t}$ $\quad H_0 d = \frac{d}{t}$ $\quad H_0 = \frac{1}{t}$ $\quad t = \frac{1}{H_0}$ ✓

(ii) State one assumption made in your derivation.

(1)

Expansion has been uniform. ✓

(iii) The parsec (pc) is a unit used for astronomical distances. 1 pc is 3.1×10^{16} m.

The accepted range for the Hubble constant H_0 is (60–80) km s^{-1} Mpc^{-1}.

Deduce whether the observation by the JWST leads to a value of H_0 within the accepted range.

1 year = 3.16×10^7 s

(3)

13×10^9 years $= 13 \times 10^9 \times 365 \times 24 \times 60^2$

$= 4.10 \times 10^{17}$ s ✓

$H_0 = \frac{1}{T} = \frac{1}{4.10 \times 10^{17}} = 2.439 \times 10^{-18}$ s^{-1} ✓

$2.439 \times 10^{-18} \div 1000 \times 3.1 \times 10^{22} = 75.6$ km s^{-1} Mpc^{-1}

into km ↑   into Mpc ↑   ∴ in accepted range ✓

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(b) The light from one of the galaxies, called Maisie, has a redshift z of 14.
The wavelength of light from Maisie detected at the telescope is 4.0×10^{-6} m and lies within the infrared section of the electromagnetic spectrum. ↖ λ_2

(i) Calculate the wavelength of light emitted by Maisie. λ_1

(3)

$z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda_2 - \lambda_1}{\lambda_1}$ ✓

$z\lambda_1 = \lambda_2 - \lambda_1$

$\lambda_1(z+1) = \lambda_2$

$\lambda_1 = \lambda_2/(z+1)$

$\lambda_1 = \frac{4.0\times10^{-6}}{14+1} = 2.67\times10^{-7}$ ✓

Wavelength emitted = 2.7×10^{-7} ✓ m

(ii) Explain why the light emitted by Maisie arrives at the telescope as infrared.

(2)

Wavelength of light has increased ✓ from the UV part of the spectrum because it is stretched due to the expanding universe. ✓

(c) One of the infrared detectors on the JWST is made from material with a work function of 0.30 eV.

Deduce whether this detector can detect the light from Maisie.

(4)

$c = f\lambda \quad f = \frac{c}{\lambda} = \frac{3.00\times10^{8}}{4.0\times10^{-6}} = 7.5\times10^{13}$ Hz ✓

$E = hf = 6.63\times10^{-34} \times 7.5\times10^{13} = 4.9725\times10^{-20}$ J ✓

convert to eV $\quad 4.9725\times10^{-20} \div 1.60\times10^{-19} = 0.31$ eV ✓

Energy of photons > work function ∴ should be detected ✓

(Total for Question 15 = 14 marks)

16 The suspension system in a car includes a spring attached to each wheel as shown.

(Source: © Macrovector/Shutterstock)

The car, of mass 1100 kg, is stationary. Each spring is compressed by 152 mm due to a quarter of the weight of the car. Each spring is well within both the limit of proportionality and the elastic limit.

(a) State what is meant by within the elastic limit.

(1)

If the load is removed, the spring will return to its original length. ✓

(b) (i) Show that the stiffness of each spring is about 18 000 N m^{-1}.

(3)

W = mg ✓ F = kx ✓ 4 wheels

mg = kx $k = \frac{mg}{x} = \frac{(1100/4) \times 9.81}{0.152}$

k = 17,748 Nm^{-1} ✓ ≈ 18,000

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(ii) A force is applied to the car which results in a further small compression of each spring. The force is then removed, and the body of the car oscillates with simple harmonic motion.

Determine the frequency of the oscillations.

(3)

$T = 2\pi\sqrt{\frac{m}{k}}$ ✓ $\therefore f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{4\times 17748}{1100}}$ ✓

$f = 1.279$

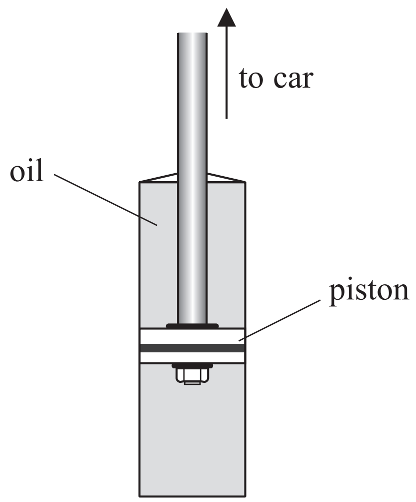
Frequency = 1.28 ✓ Hz

(c) State the conditions for simple harmonic motion.

(2)

Acceleration is proportional to the displacement from the equilibrium position ✓ and in the opposite direction to the displacement. ✓

(d) The oscillations are heavily damped by a piston in the suspension system. The piston moves within a cylinder filled with oil, as shown. The oil has a high viscosity.



Explain why using oil of high viscosity will produce heavy damping.

(3)

The high viscosity oil produces a large resistive force to the oscillations. ✓ As the piston moves, a large amount of work will be done ✓ and the energy of the oscillation will be transferred to the oil ∴ heavy damping. ✓

(Total for Question 16 = 12 marks)

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17 Scientists can analyse light from stars that has passed through a diffraction grating.

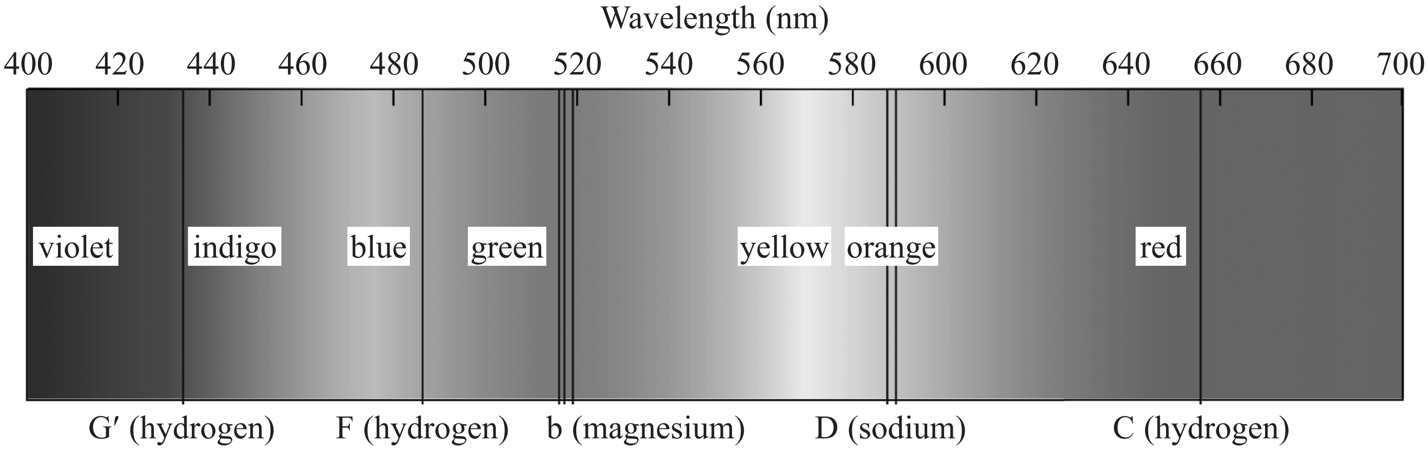
*(a) Explain the pattern produced when a mixture of blue and red light, from the same source, passes through a diffraction grating.

(6)

Waves from different slits undergo superposition. Constructive interference occurs when the path difference = $n\lambda$ which produces bright lines on a screen. The central maxima is due to red and blue light mixing, so will appear magenta.

As $n\lambda = d \sin\theta$, for a longer wavelength $\sin\theta$ is greater and θ will be greater. Blue λ shorter than red λ ∴ the blue will be less spread out and the first blue maxima will be closer to the centre than the first red maxima.

(b) A spectrum of the visible light emitted by a particular star is shown.



(Source: © Universal Images Group North America LLC/Alamy Stock Photo)

(i) Light interacts with atoms as it passes through the atmosphere of the star.

Explain how this leads to the formation of the dark lines within the spectrum.

(4)

Electrons exist in discrete energy levels. Absorbing a photon causes an electron to jump to a higher energy level. Photons are only absorbed when the photon energy = difference between energy levels, and the photon energy $\propto f$ $\therefore$ only certain frequencies of light from the centre of the star are absorbed, then re-emitted in all directions, by the gases in the outer atmosphere.

(ii) The surface temperature of the star is 5800 K.

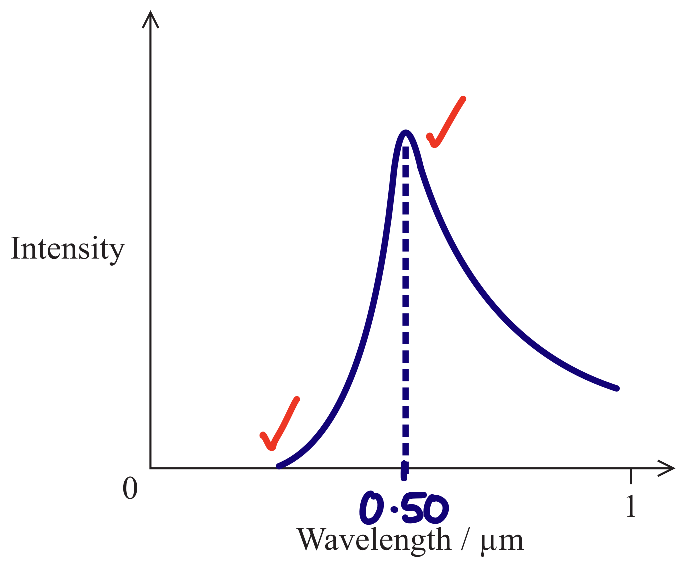
On the axes below, sketch a graph of the intensity of radiation against the wavelength of that radiation for this star.

(4)

$\lambda_{max} T = 2.898 \times 10^{-3}$ mK ✓

$\lambda_{max} = \dfrac{2.898 \times 10^{-3}}{5800} = 4.997 \times 10^{-7}$ m ✓

$= 0.50 \times 10^{-6}$ m



(iii) This star is a main sequence star.

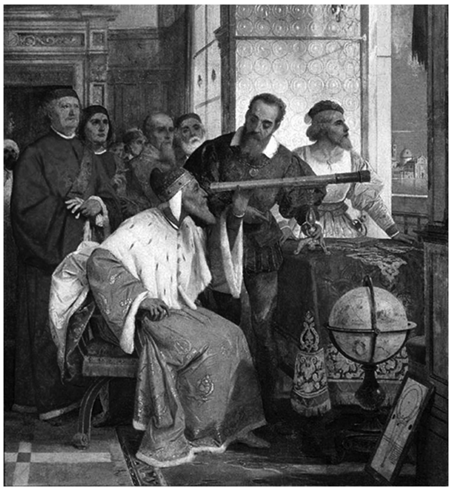
Explain why main sequence stars do not collapse due to gravitational forces.

(2)

Nuclear fusion releases energy ✓, producing an outward radiation pressure which balances the inward gravitational forces. ✓

(Total for Question 17 = 16 marks)

18 Galileo is credited with inventing the first telescope in 1610. The picture shows an early demonstration of the telescope.



(Source: © CPA Media Pte Ltd/Alamy Stock Photo)

A converging lens was positioned at one end of the telescope. A diverging lens was placed at the other end and a person looked through this lens.

(a) The converging lens produced an image at a distance equal to the focal length of the lens.

Explain what can be concluded about the object being viewed.

(2)

Rays must be parallel to converge at focal length ✓ ∴ object must be far away. ✓

(b) The final image produced by the telescope is described as virtual and upright.

State what is meant by virtual and upright.

(2)

Virtual

Real rays of light do not pass through the image position. ✓

Upright

Image is the same way up as the original object. ✓

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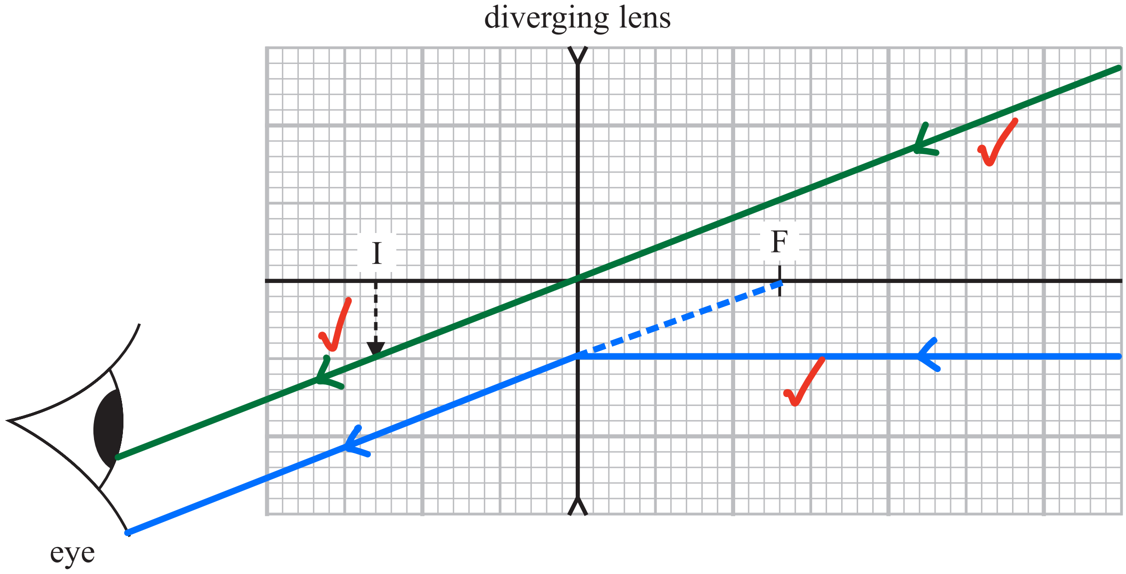
(c) The image, I, produced by the converging lens is at a distance from the diverging lens equal to the focal length of the diverging lens, as shown. This image acts as an object for the diverging lens.



The distance equal to the focal length on the other side of the lens is marked with F.

Draw the ray diagram for the diverging lens.

(3)

(d) Galileo's first telescope had a magnification of 10, and a distance between the centres of the two lenses of 90 cm.

$$\text{The magnification of the telescope} = \frac{\text{focal length of converging lens}}{\text{focal length of diverging lens}}$$

Calculate the focal length of each lens.

(2)

$m = \frac{f_c}{f_d} = 10$ $\quad f_c = 90 + f_d$

$\frac{90 + f_d}{f_d} = 10$ $\quad 90 + f_d = 10 f_d \quad f_d = 90/9 = 10\text{ cm}$

$f_c = 90 + f_d = 90 + 10 = 100\text{ cm}$

Focal length of converging lens = 100 cm ✓

Focal length of diverging lens = 10 cm ✓

(e) Galileo was the first person to observe Jupiter's larger moons.

Ganymede is Jupiter's largest moon. The distance between the centre of Ganymede and the centre of Jupiter is 1.07×10^6 km. Ganymede takes 171 hours to complete an orbit around Jupiter.

Calculate the mass of Jupiter.

(5)

171 hours $= 171 \times 60^2 = 615{,}600$ s ✓

$\frac{GmM}{r^2} = \frac{mv^2}{r}$ ✓ $v = \frac{2\pi r}{T}$

$M = \frac{4\pi^2 r^3}{GT^2}$

$v^2 = \frac{4\pi^2 r^2}{T^2}$

$\frac{GM}{r} = v^2$

$M = \frac{4 \times \pi^2 \times (1.07 \times 10^9)^3}{6.67 \times 10^{-11} \times 615{,}600^2}$ ✓

$\frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$ ✓

$M = 1.913 \times 10^{27}$

Mass of Jupiter = 1.91×10^{27} ✓ kg

(Total for Question 18 = 14 marks)

TOTAL FOR PAPER = 90 MARKS

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List of data, formulae and relationships

Acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$	
Coulomb law constant	$k = \dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19}\ \text{C}$	
Electron mass	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	
Electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	
Gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	
Gravitational field strength	$g = 9.81\ \text{N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27}\ \text{kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27}\ \text{kg}$	

Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

moment of force $= Fx$

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \tfrac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

$$P = \frac{E}{t}$$

$$P = \frac{W}{t}$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{el} = \tfrac{1}{2}F\Delta x$$

Waves and particle nature of light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

Intensity of radiation

$$I = \frac{P}{A}$$

Power of a lens

$$P = \frac{1}{f}$$

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin \theta$$

Refractive index

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \tfrac{1}{2}mv^2_{max}$$

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

Further mechanics

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

$$E_k = \frac{p^2}{2m}$$

Motion in a circle

$$v = \omega r$$

$$T = \frac{2\pi}{\omega}$$

$$F = ma = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$a = r\omega^2$$

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \tfrac{1}{2}\frac{Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = BIl \sin\theta$$

$$F = Bqv \sin\theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$$

Root-mean-square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = 4\pi r^2\sigma T^4$$

Wien's law

$$\lambda_{max}T = 2.898 \times 10^{-3}\ \text{m K}$$

Space

Intensity

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{½}}$$

$$N = N_0\ \mathrm{e}^{-\lambda t}$$

$$A = A_0\ \mathrm{e}^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos\omega t$$

$$v = -A\omega\sin\omega t$$

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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