AQA

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname ______________________

Forename(s) ______________________

Candidate signature ______________________

A-level
PHYSICS

Paper 3
Section B Turning points in physics

Thursday 14 June 2018 Morning

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:
- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
TOTAL	

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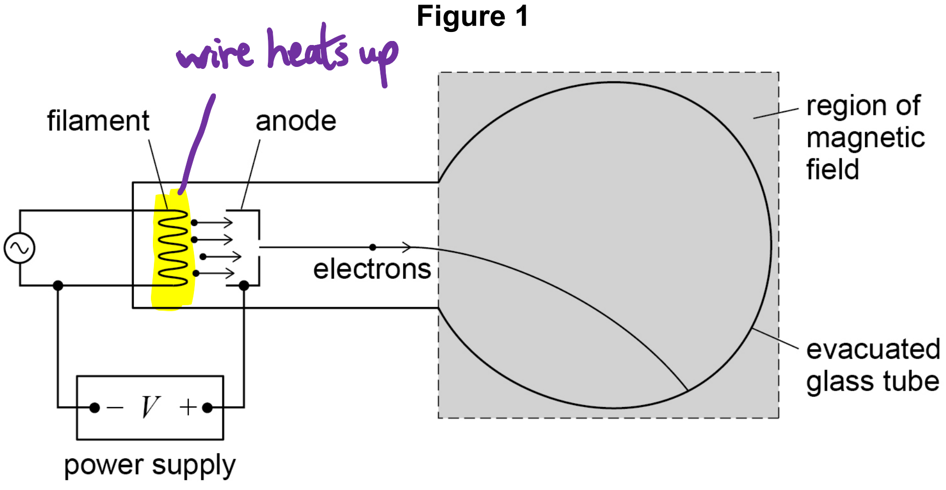
Section B

Answer **all** questions in this section.

0 1 **Figure 1** shows apparatus which can be used to determine the specific charge of an electron.

Figure 1



Electrons are emitted from the filament and accelerated by a potential difference between the filament and anode to produce a beam. The beam is deflected into a circular path by applying a magnetic field perpendicular to the plane of the diagram.

0 1 . 1 Describe the process that releases the electrons emitted at the filament.

[3 marks]

- The process is called thermionic emission ✓
- The current in the wire causes it to heat up ✓
- Increasing the temperature of the metal will increase the kinetic energy (and therefore thermal energy) of the electrons, until they are able to leave the surface of the metal ✓

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0 1 . 2 **Table 1** shows the data collected when determining the specific charge of the electron by the method shown in **Figure 1**.

Table 1

potential difference V that accelerates the electrons	320 V
radius r of circular path of the electrons in the magnetic field	4.0 cm
flux density B of the applied magnetic field	1.5 mT

$= 0.04\,m$

$= 1.5\times10^{-3}\,T$

Show that the specific charge of the electron is given by the expression $\dfrac{2V}{B^2r^2}$

[2 marks]

$\rightarrow = \frac{e}{m}$

energy $= \frac{1}{2}mv^2$ (kinetic; m: mass of electron; v: speed of electron)

$= eV$ (e: charge on electron; V: accelerating p.d.)

$eV = \frac{1}{2}mv^2$ ✓, force on electron $= Bev = \frac{mv^2}{r}$ (magnetic; centripetal; r: radius)

$v = \sqrt{\frac{2eV}{m}} = \frac{Ber}{m} \Rightarrow \frac{e}{m} ✓ = \frac{1}{Br}\sqrt{\frac{e}{m}}\sqrt{2V} = \frac{2V}{B^2r^2}$

0 1 . 3 Using data from **Table 1**, calculate a value for the specific charge of the electron.
Give your answer to an appropriate number of significant figures.

[2 marks]

$B = 1.5\times10^{-3}\,T$

$V = 320\,V$

$r = 0.040\,m$

$\frac{e}{m} = \frac{2V}{B^2r^2}$

$= \frac{2\times320}{(1.5\times10^{-3})^2\times0.04^2}$ ✓

$= 1.7777\times10^{11}\,C\,kg^{-1}$

$\simeq 1.8\times10^{11}\,C\,kg^{-1}$ ✓

specific charge of the electron = 1.8×10^{11} C kg^{-1}

Question 1 continues on the next page

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0 1 . 4 At the time when Thomson measured the specific charge of the particles in cathode rays, the largest specific charge known was that of the hydrogen ion.

State how Thomson's result for the specific charge of each particle within a cathode ray compared with that for the hydrogen ion and explain what he concluded about the nature of the particles. = e/m

[2 marks]

- The specific charge of the particles in cathode rays was greater than that of a hydrogen ion ✓

- The charge of the cathode rays was larger compared to the mass, so they consisted of electrons with a low mass and a high magnitude of charge ✓

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0 2 **Figure 2** shows a modern version of the apparatus used by Hertz to investigate the properties of electromagnetic waves. Electromagnetic waves are continuously emitted from a dipole transmitter. The electromagnetic waves are detected by a dipole receiver.
An oscilloscope is used to display the amplitude of the detected signal at the dipole receiver.

Figure 2

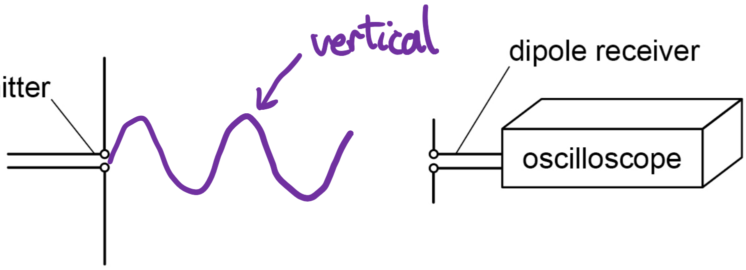
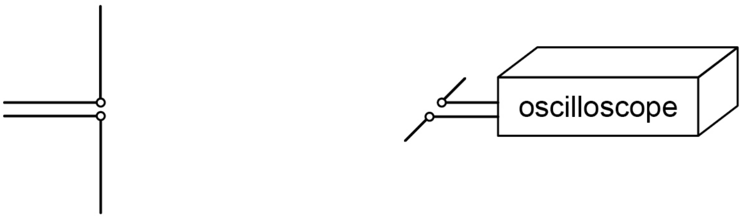


Figure 3 shows the same apparatus when the dipole receiver has been rotated through an angle of 90°

Figure 3



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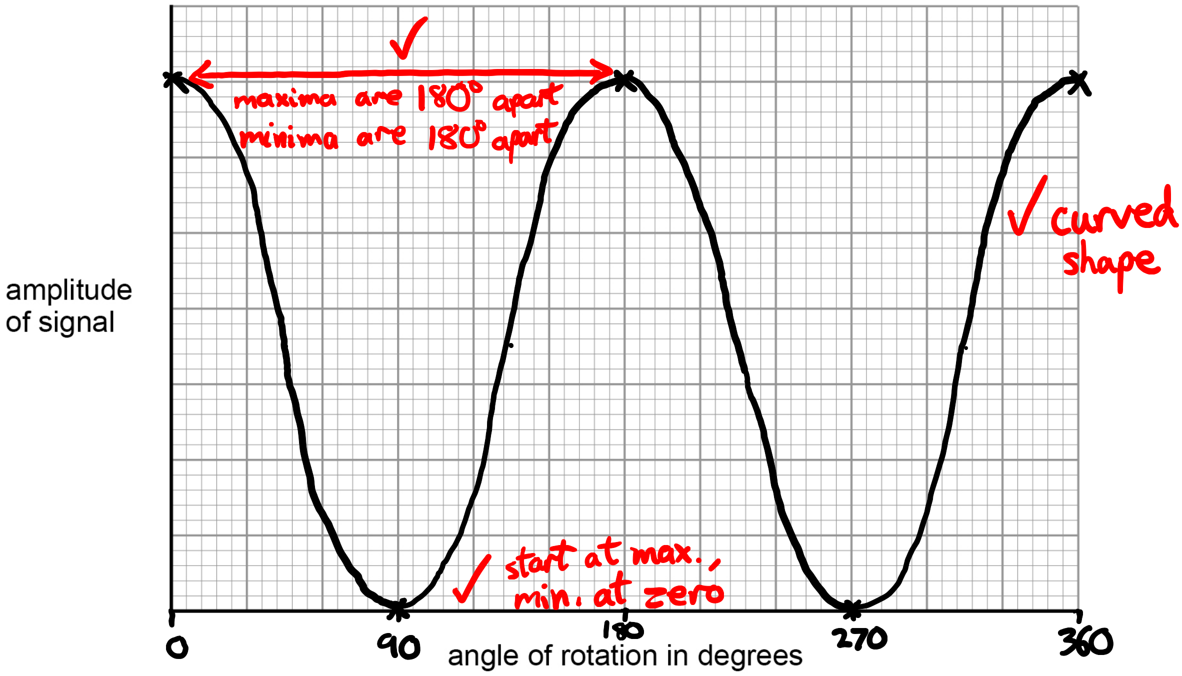
0 2 . 1 Sketch a graph on **Figure 4** to show how the amplitude detected by the dipole receiver varies with angle of rotation as the receiver is turned through $360°$
Start your graph from the position shown in **Figure 2**.

[3 marks]

Figure 4



0 2 . 2 Maxwell derived the equation $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$ for the speed c of electromagnetic waves,

where μ_0 is the permeability of free space and ε_0 is the permittivity of free space.

Explain, using a suitable calculation, why this equation led to the conclusion that light is an electromagnetic wave.

[2 marks]

$\mu_0 = 4\pi \times 10^{-7}\,\text{T m A}^{-1}$

$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F m}^{-1}$

$$c = \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.85 \times 10^{-12}}} = 2.9986 \times 10^{8}\,\text{m s}^{-1} \simeq 3.0 \times 10^{8}\,\text{m s}^{-1}$$ ✓

• The experimental value determined for the speed of light is similar to the calculated speed of electromagnetic waves. ✓

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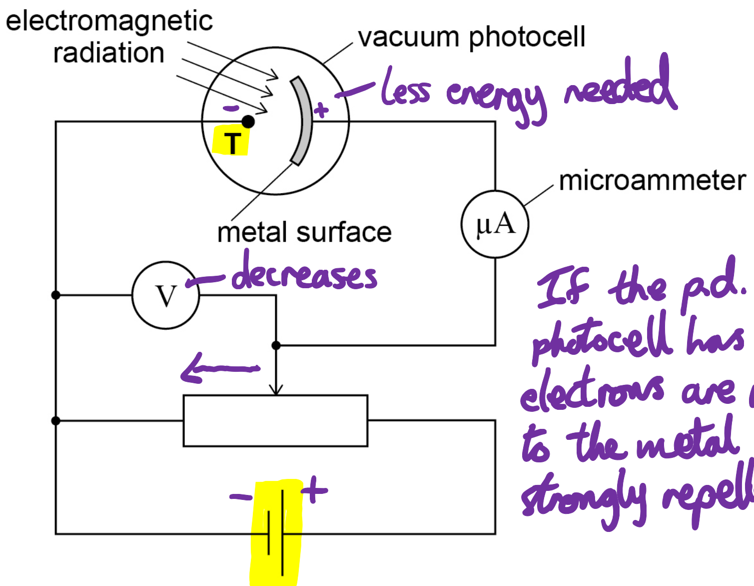
0 3 **Figure 5** shows a vacuum photocell in which a metal surface is illuminated by electromagnetic radiation of a single wavelength. Electrons emitted from the metal surface are collected by terminal **T** in the photocell. This results in a photocurrent, I, which is measured by the microammeter.

Figure 5



If the p.d. across the photocell has a higher magnitude, electrons are more strongly attracted to the metal surface and more strongly repelled from T

The potential divider is adjusted until the photocurrent is zero.

The potential difference shown on the voltmeter is 0.50 V — each electron has $0.50\,eV = 8.0\times10^{-20}\,J$

The work function of the metal surface is 6.2 eV

0 3 . 1 Calculate the wavelength, in nm, of the electromagnetic radiation incident on the metal surface.

[3 marks]

$1\,eV = 1.6\times10^{-19}\,J$

$6.2\,eV = 6.2\times1.6\times10^{-19}\,J$
$= 9.92\times10^{-19}\,J$ ✓

Incoming photons have an energy of $(9.92\times10^{-19}) + (8.0\times10^{-20})$
$= 1.072\times10^{-18}\,J$ ✓

$E = \frac{hc}{\lambda}$ (E – energy of photon; h – Planck constant; c – speed of light; λ – wavelength of photon)

$\Rightarrow \lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.072\times10^{-18}} = 1.86\times10^{-7}\,m$

wavelength = 186 ✓ (≃190) nm

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0 3 . 2 The intensity of the electromagnetic radiation is increased. No adjustment is made to the potential divider.

The classical wave model and the photon model make different predictions about the effect on the photocurrent.

Explain the effect on the photocurrent that each model predicts and how experimental observations confirm the photon model.

✓ correct predictions

[3 marks]

Classical Wave Model

2×✓, one for a point made in each model

- Electrons will eventually gain enough kinetic energy to reach T
- With enough intensity, the energy gained by the electrons will be greater, so they leave the surface with more kinetic energy
- This predicts an increase in the photocurrent

Photon Model → dependent on frequency, not intensity

- The energy of a photon is not high enough to give sufficient kinetic energy to an electron, so the photocurrent is not predicted to change

0 3 . 3 The potential divider in **Figure 5** is returned to its original position so that a photocurrent is detected by the microammeter.
The potential divider is then adjusted to increase the potential difference shown on the voltmeter.

Explain why the photocurrent decreases when this adjustment to the potential divider is made.

[2 marks]

- If the reading on the voltmeter is higher, the electrons need more energy to cross the gap ✓
- Fewer electrons reach T in every unit time, so the rate of flow of electrons (and therefore charge) in the circuit decreases ✓

Question 3 continues on the next page

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0 3 . 4 The apparatus shown in **Figure 5** is used to investigate three different metal surfaces **A**, **B** and **C**.

Table 2 shows, for each of the three surfaces, a voltmeter reading V and the corresponding photocurrent I. The same source of electromagnetic radiation is used throughout the investigation.

Table 2

	V / V	I / μA
Metal surface **A**	1.5	56
Metal surface **B**	2.5	56
Metal surface **C**	2.5	78

Which conclusion about the relationship between the work functions of **A**, **B** and **C** is correct?

Tick (✓) the correct box.

[1 mark]

A > B > C ☐

A < B < C ☐

B > A > C ☐

B < A < C ☐

9

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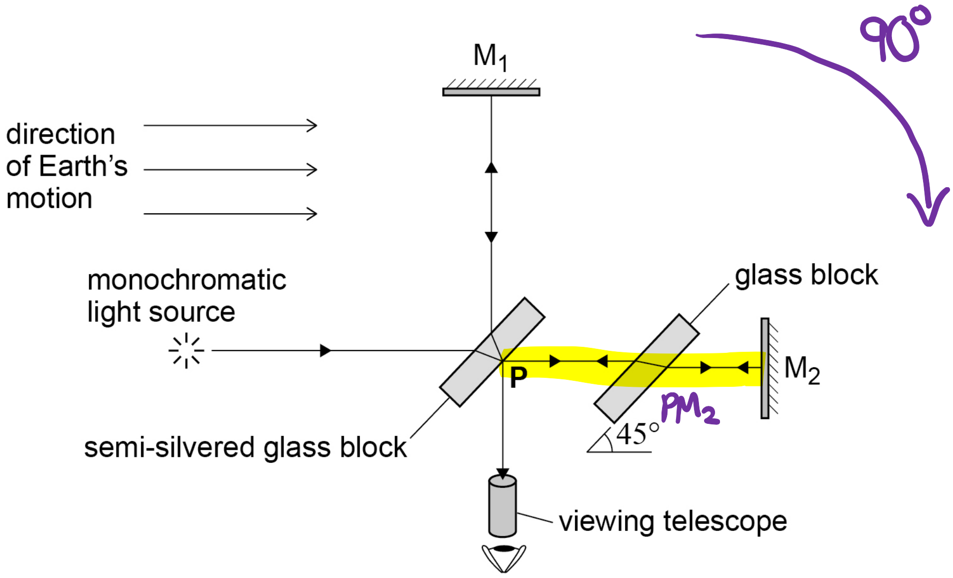
0 4 **Figure 6** shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

Light from the monochromatic source passes through the semi-silvered glass block and takes two different paths to the viewing telescope. The two paths, PM_1 and PM_2, are the same length. Interference fringes are observed through the viewing telescope.

Figure 6



It was predicted that when the interferometer was rotated through 90° the fringe pattern would shift by 0.4 of the fringe spacing.

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0 4 . 1 Explain how the experiment provided a means of testing the idea that the Earth had an absolute motion relative to the ether.

Your answer should include:

- an explanation of why a shift of the fringe pattern was predicted
- a comparison of the results of the experiment to the prediction
- the conclusion about the Earth's absolute motion through the ether.

[6 marks]

Why was a shift predicted?

- The line from P to M_2 is in the same direction as the velocity of the Earth
- The speed of light was expected to be different in the two directions, relative to the ether
- With this difference in speed the light should take a longer time to go from P to M_2 and back than from P to M_1 and back
- Rotating the apparatus through 90° should cause the travel times to swap, meaning that the time difference is reversed
- Changing this time difference would cause the phase difference to change, meaning the observer would see a different pattern

Comparing the results to the prediction

- The apparatus was able to detect shifts of 0.05 fringe
- No change was observed in this experiment or any later ones

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Conclusions made

- The experiment showed that there is no absolute motion
  - → Absolute motion is relative to a universal stationary rest frame
  - → In reality, all motion is relative
- The ether does not exist, so light can travel without any material medium
- The Earth was dragging the ether with it

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0 4 . 2 The Michelson-Morley experiment provides evidence for one of the postulates of Einstein's theory of special relativity.

State this postulate.

[1 mark]

The speed of light is the same in free space ✓

can also say "vacuum"

0 4 . 3 State the other postulate of Einstein's theory of special relativity.

[1 mark]

The same laws of physics apply in any inertial frame of reference ✓

Question 4 continues on the next page

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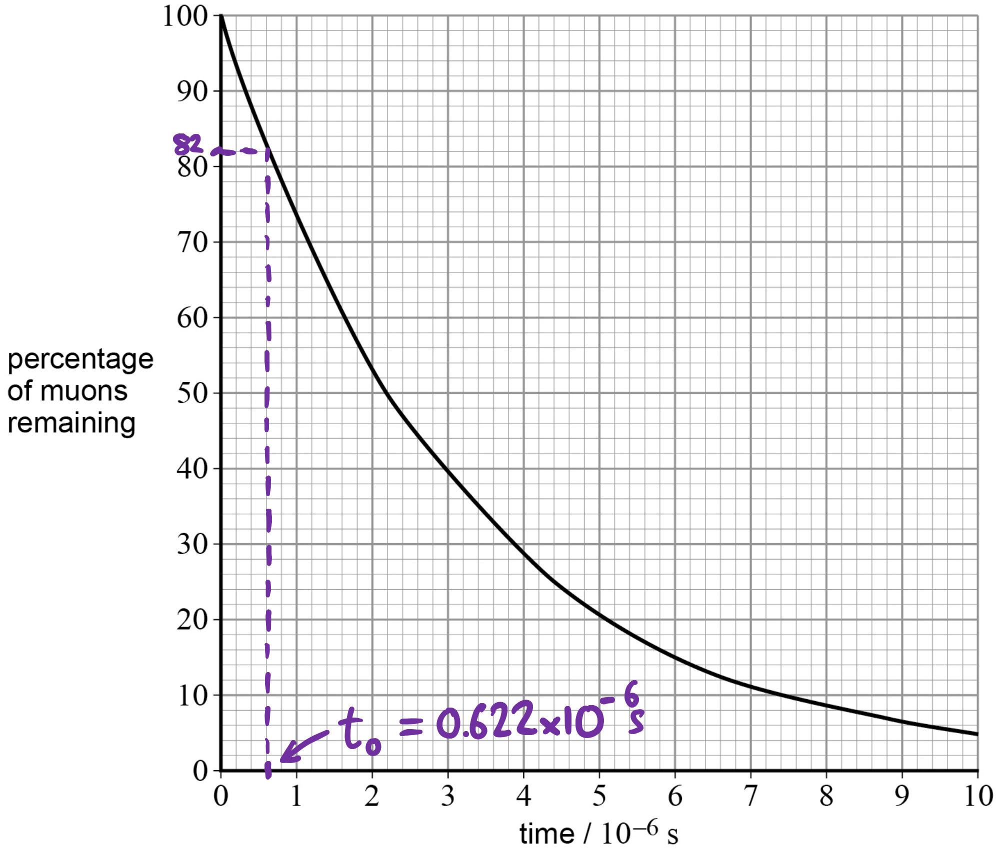
0 4 . 4 One consequence of the special theory of relativity is length contraction.

Experimental evidence for length contraction is provided by the decay of muons produced in the atmosphere by cosmic rays.

Figure 7 shows how the percentage of the number of muons remaining in a sample changes with time as measured by an observer in a frame of reference that is stationary relative to the muons.

Figure 7



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In a particular experiment, muons moving with a velocity 0.990c travel a distance of 1310 m through the atmosphere to a detector.

99% of speed of light

Determine the percentage of muons that reach the detector.

[4 marks]

$$\text{Time of flight} = \frac{\text{distance}}{\text{speed}} = \frac{1310}{0.99 \times 3 \times 10^8}$$

$$= 4.41 \times 10^{-6}\,s$$ ✓

proper time (experienced by muons)

$$t_0 = t\sqrt{1 - \frac{v^2}{c^2}}$$

speed of muons

speed of light

time in stationary frame

$$= 4.41 \times 10^{-6}\sqrt{1 - \frac{(0.990c)^2}{c^2}} = 6.22 \times 10^{-7}\,s$$ ✓ ✓

Reading from the graph, 82% are remaining

percentage = 82 (±1) % ✓

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Alternate Method

$$L = 1310\sqrt{1 - 0.99^2} = 185\,m$$ ✓ ✓

contracted length

$$t_0 = \frac{L}{v} = \frac{185}{0.99 \times 3 \times 10^8}$$ ✓

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