Mark schemes

1. (a) Weight/gravitational force AND electric/electrostatic force ✓

Equal (magnitudes) and opposite directions,

AND one direction at least specified ✓

The second mark is conditional on the first.

First mark is for naming the two forces.

Condone 'electromagnetic' for 'electric'

Do not allow field or potential for force.

Allow "force due to electric field"; "force due to magnetic field"

Penalise additional forces in MP2.

The second mark is for the relationship between them. Must include idea of size and direction.

e.g. weight down equals E force up/towards positive plate/away from negative plate.

Do not allow 'balanced' or 'in equilibrium' for equals

The forces can be in the form of formulae for MP1 and MP2 (e.g. Eq, EV/d, mg)

2

(b) $m = 4\pi r^3\rho/3$ and $mg = 6\pi\eta rv$ seen ✓

$r^2 = 18\ \eta v / 4\ \rho g$ is seen in in some form, in symbols or through substituted data, ✓

Correct use of equations to obtain $r = 9.7 \times 10^{-7}$ m ✓

Do not allow backward calculation

Can be seen by substitution.

Can be seen in single equation:

$4\pi r^3\rho g/3 = 6\pi\eta rv$

Do not award if v and V confused

Do not condone 1sf answer.

Must be clear answer refers to r, not r^2 for example.

If no other mark given MP1 can be awarded if F used for mg, and/or volume AND density equations seen separately

3

(c) The number of excess electrons on the droplet is 3 ✓

In order for each half to remain stationary, the charge would have to split equally
OR
Due to the quantisation of charge, the charge cannot split equally ✓

It is not possible for both droplets to remain stationary / the student is wrong ✓

May be seen in terms of values of charge or e

Award for idea that charge would have to be 1.5e

Evidence for MP1 and MP2 may be seen together. E.g. charge on drops are e and 2e, OR 1.6×10^{-19} *and* 3.2×10^{-19}

Ignore reference to particles repelling each other

3

[8]

2. (a) Filament / metal is heated due to the current through it ✓

OR

Temperature of the filament rises due to the current through it

(Free / conduction) electrons gain sufficient/enough (kinetic) energy to leave (the metal surface)

OR

Work function (defines work function) ≤ energy supplied to an electron/electron energy ✓

Thermionic emission ✓

Not

Electrons are heated

Not heated due to the pd across it

Allow

By electrical power or electrically heated

Not allowed

Reference to electrons leaving <u>atoms</u> or ionisation

Allow

Energy supplied sufficient to overcome the work function

3

(b) Use one of $\frac{1}{2}mv^2 = eV$ and $r = \frac{mv}{Be}$ or $\frac{mv^2}{r} = Bev$

To arrive at

$\frac{Ber}{m} = v$ or $v = \sqrt{\frac{2eV}{m}}$ or $v^2 = \frac{2eV}{m}$

or $\frac{e}{m} = \frac{v}{Br}$ or $\frac{e}{m} = \frac{v^2}{2V}$ ✓

Substitution in the other equation and manipulates correctly and clearly to give $\frac{e}{m} = \frac{2V}{B^2r^2}$ ✓

Condone q for e

Substitution in other equation and correct manipulation

NB this is a show that so mark is not simply for stating the equation given

I presented such that v (velocity) and V (voltage) are indistinguishable in manipulation then award only first mark

2

(c) Correct substitution $\frac{e}{m} = \frac{2 \times 320}{(1.5 \times 10^{-3})^2 \times 0.040^2}$

And answer 1.8×10^{11} ✓

Answer to 2 sig figs ✓

Allow for incorrect answer following incorrect substitution in equation

As answer is on the data sheet must see correct substitution with all correct powers of ten

2

(d) The specific charge of the cathode rays/the particles was(much) larger/greater than the hydrogen ion/proton ✓

This provided evidence that cathode rays were composed of electrons/particles which have a (very) small mass / have a high (negative) charge

OR

Mass (much) smaller than the mass of a hydrogen (ion)/proton ✓

Not higher

If mark 1 not given then 0 for the question

Not lightest as substitute for mass

2

[9]

3. (a) Cathode rays/electrons move from cathode toward anode

Accept move left to right.

1

The paddle wheel has gained energy from cathode rays/electrons. ✓

Accept as alternatives for energy kinetic,

energy/momentum/impulse ✓

Ignore references to force.

Ignore references to applying a magnetic field.

1

(b) Electrons are pulled out/escape from atoms OR gas atoms are ionised ✓

Condone molecules as alternative to atoms.

1

(Positive ions generated near the cathode are attracted to the cathode causing free) electrons emitted from the cathode.✓

1

Electrons are accelerated toward the anode (by the potential difference) ✓

Do not accept attraction as an alternative to acceleration.

1

(c) Reason: Idea of fewer electrons/cathode rays ✓

Effect: Paddle wheel rotates less ✓

Must score the reason mark to score the effect mark.

Ignore references to air resistance.

OR

Reason: Idea of electrons/cathode rays have higher energy/speed /momentum ✓

Effect: Paddle wheel rotates more ✓

If no mark is awarded, one mark can be awarded for the effect of the paddle wheel rotating more where the reasoning is limited to less collisions of electrons with air molecules.

2

[7]

4.

(a) 2 From ✓✓

(High) electric field pulls electrons from (gas) atoms/ ionises (gas) atoms

positive ions in tube are accelerated to C/cathode and strike surface/electrons in surface

Electrons (in cathode) emitted and accelerated towards A (and B) (to form cathode ray).

Do not award MP3 if there is a suggestion of a p.d. between A and B

2

(b) Y to X ✓

1

(c) Reference to v = E/B (when path straight) ✓

(Eg Electric force = magnetic force

Eq= Bqv

v = E/B)

(Therefore for greater v)

Either increase E ✓

Or decrease B. ✓

For MP2 and MP3 there must be some correct supporting theory e.g. $F_M = Bqv$

3

(d) (Magnitude of) specific charge much greater (approximately x 2000) specific charge of hydrogen (ion), (largest then known). ✓

(If charges similar) Cathode rays particles mass much smaller than hydrogen ion and therefore smaller than atom. ✓

Do not condone "he deduced they were electrons"

MP2 cannot be awarded if MP1 is incorrect.

If no other creditable answer given, one mark can be awarded for stating that the sign of the specific charge of cathode ray is opposite to that of hydrogen ion.

2

[8]

5.

(a) **A** is filament ✓

B is the anode ✓

V_1 is the p.d. to supply energy/ drive current to heat **A**. ✓

V_2 is the p.d./produces accelerating electric field to accelerate electrons.

Allow heated cathode

(b) (Atom diameter about 0.1 nm)

Allow 0.05 nm to 0.1 nm for wavelength

So wavelength should be about 0.05 nm ✓

$\lambda = \frac{h}{\sqrt{2meV}}$ seen ✓

Ecf for wavelength for MP 2, 3, 4

Rearranged with substitutions of h, m, e to give

$V = \frac{h^2}{2me\lambda^2}$ ✓

= 600 V ✓

Allow 1 sf answer

4

(c) State inverse relationship between wavelength and momentum✓

De Broglie hypothesis suggests that λ will decrease/increase if the momentum increases/decreases

Identify link between V_2 and momentum of electrons. ✓

Allow qualitative statements.

Measure V_2 to determine (KE of electrons and therefore) momentum/speed of electrons

Identify how ring diameter is related to wavelength. ✓

Measure ring diameter as increased/decreased diameter indicates increased/decreased wavelength

State change in ring diameter due to change in V_2 (which is consistent with de Broglie hypothesis) ✓

(De Broglie hypothesis therefore supported by)

increasing/decreasing V_2 resulting in decreased/increased ring diameter.

4

(d)

STM	TEM	
Moving electrons can cross a potential barrier.	Moving electrons can be deflected by a magnetic field.	✓
Moving electrons can be deflected by a magnetic field.	Moving electrons can be deflected by a magnetic field.	
Moving electrons can be deflected by a magnetic field.	Moving electrons can cross a potential barrier.	
Moving electrons can cross a potential barrier.	Moving electrons can cross a potential barrier.	

Tick in first box ✓

Only answer

1

[13]

6. (a)

	Tick (✓) if correct
Beta particle emission	
Electron diffraction	
Photoelectric effect	
Thermionic emission	✓

1

(b) Use of $\lambda = \frac{h}{\sqrt{(2mE)}}$ seen including correct substitution

1

$\lambda = 2.4 \times 10^{-11}$ (m)

1

Statement to the effect that this is similar to or less than 0.1 nm/atomic dimension/diameter of the atom (so individual atoms can be resolved).

1

Condone missing unit

Allow a correct conclusion that follows from an incorrect value of λ

3

(c) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.**

Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria	QoWC
6	At least six of the likely statements will be covered to a good standard including at least three from image formation and at least three from quality and detail.	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.
5	At least five of the likely statements will be covered to a good standard including at least two from image formation and at least one from quality and detail.	
4	At least three of the likely statements will be covered to a good standard. The response must include one of both image formation and factors affecting quality and detail.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.
3	At least two of the likely statements will be covered to a good standard. The response must include one of both image formation and factors affecting quality and detail.	
2	At least two of the likely statements from image formation or quality and level of detail will be covered to a good standard. The other area (if covered) will have errors and omissions.	The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.
1	One of the likely statements will be covered to a good standard.	

0	No relevant coverage of the likely statements.	The student's presentation, SP&G seriously obstruct understanding..

The following statements are likely to be present.

Process of Image formation

- Electrons through the middle of the lenses are undeviated
- Electrons on the edges are deflected by magnetic fields toward the axis of the TEM
- The condenser lens deflects the electrons into a wide parallel beam incident uniformly on the sample.
- The objective lens then forms an image of the sample.
- The projector lens then casts a second image onto the fluorescent screen.

Factors affecting the quality and level of detail

- Wavelength depends on speed of the electrons
- Lower the wavelength gives greater the detail.
- Emitted electrons come from a heated cathode and therefore have a speed distribution dependent on temperature.
- The speed of the electrons is not always the same which causes different pathways through the lens and so aberration.
- The sample thickness reduces the speed of the electrons increasing the wavelength and decreasing the detail.

[6]

7. (a) Observation A – When rotation speed is low the light returns through the original gap. ✓

Condone an answer where candidate has substituted tooth for gap throughout.

1

Observation B – The light is blocked when it hits an adjacent tooth on return from the mirror. ✓

1

(b) $c = 4 \times 8600 \times 720 \times 12 = 2.97 \times 10^8\ ms^{-1}$ ✓

1

Comparison to speed of light $3.0 \times 10^8\ ms^{-1}$ and judgement that they are similar. ✓

Speed of light must be given to 2 or 3 significant figures.

1

(c) Must go past a gap and to the next tooth ✓

Accept a clear diagram as an alternative

36 rotations per second / Hz ✓

2

(d) Maxwell's theory of electromagnetic waves predicted a value for the speed of electromagnetic waves ✓

Fizeau's result is close to the predicted speed (of electromagnetic waves) ✓

Implies that light is an electromagnetic wave. ✓

3

[9]

8. (a) Unchanged Changed

1

(b) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.**

Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria	QWC
6	All 3 areas A, B and C covered Only allow minor omissions	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.
5	2 complete descriptions with one partial from A, B and C	
4	Full description of one area, with partial description of other two OR Full descriptions of two areas with very little on third or nothing at all	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.
3	A full description of one area and a partial description of one area OR A partial discussion of all three areas	
2	A full discussion of one area OR A partial discussion of two areas	The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.
1	Only one area covered, and that partially	
0		

The following statements are likely to be present.

Area A

Description of corpuscular explanation of refraction

i) Light is made up of particles/corpuscles

ii) Force acts attracting them to the water.

iii) Attraction only affects motion at the interface/boundary.

iv) Only one component of velocity / momentum (vertical) changes at the interface.

v) The (vertical component of) velocity / momentum increases which causes the change in direction.

Partial answers may be missing idea of Force (ii) or component AND boundary (iv)(iii)

Area B

Description of wave explanation of refraction

i) Wave front is incident on interface

ii) Huygens secondary wavelets at wave fronts.

iii) Wavelets travel more slowly in the water.

iv) The slowing down of the waves / wavelets causes the change in direction.

A partial answer may have no reference to wavelets

Area C

Acceptance of wave theory

Discussion of speed:

(Newton's theory required light to travel faster in the water.

And

Huygens' theory required light to move more slowly in the water.)

When the speed of light was measured in water, the value found supported Huygens' prediction.

Discussion of wave properties

Light was observed to show interference effects that cannot be explained using corpuscular theory.)

Interference effects in Young's double slit experiment can be explained by Huygens' wave theory but not by Newton's corpuscular theory.

A partial answer will refer to only one piece of evidence.

(c) (vibrations of) the electric wave/field and magnetic wave/field are:
perpendicular to each other ✓
perpendicular to the labelled direction of motion ✓
in phase with each other ✓

Names of both waves needed for first mark

But condone missing labels (E and B) on diagram if mentioned in text

Condone single arrow unlabelled to represent direction of travel

But Reward unlabelled arrow on axis only if no arrows on other axes

Credit writing over poor diagram

3

[10]

9. (a) Pattern shows:

Maximum at start and shows minimum of zero (never negative) ✓

Correct periodicity zeros/maxima 180° apart ✓

(ie angles in right places)

Curvature rather than spikes ie  ✓ ×

(The graph should fall to zero – (NB First and last parts should ideally be curved not as illustrated here)

If negative then can get second mark only

Assume that bottom of graph grid is zero unless otherwise stated

Must be numbers on x-axis

Ignore if graph shows what happens beyond 360

If only one minimum shown then loses this mark

Allow if shown starting at zero

Freehand sketch so allow if clear attempt to show curvature in most of sketch or arches

3

(b) Correct substitution leading to a calculation of the speed of electromagnetic wave

$\frac{1}{\sqrt{(4\pi\times10^{-7})(8.85\times10^{-12})}}$ = 3.0 (2.9986) × 10^8 m s^{-1}

1

Comment that this speed agrees with the measured speed of light

Or speed determined from experiments

Or similar to Fizeau's result

1

[5]

10. (a) Converts 6.2 eV, 0.5 eV or 6.7 eV to J
eg $6.2 \times 1.6 \times 10^{-19}$ J or $9.9(2) \times 10^{-19}$ seen
for 0.5 eV 8.0×10^{-20} seen
for 6.7eV 1.07×10^{-18} seen ✓

$\lambda = \frac{hc}{E}$ or substitution $E = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda}$

With one of the above values included for energy✓

190 (185,186 or 187) nm ✓

NB use of λ=h/mv is a PE and scores 0

May use $f = \frac{E}{h}$ *and then* $\lambda = \frac{c}{f}$

Treat incorrect E in the same way

Guidance

Use of 0.5 eV gives 4.0×10^{-25}

6.2 eV 3.2×10^{-26}

6.7 eV 3.0×10^{-26}

These will score 1

8.0×10^{-20} *gives 2500 nm*

$9.9(2) \times 10^{-19}$ *200 nm*

These will score 2

1 sf answers are not allowed so correct working with answer 186 nm rounded to 200 nm will also score 2

1
1
1

(b) **Classical Wave Model**

Wave model predicts an increase in the photocurrent
Plus one from

- As energy transferred into each electron increases (over time) /energy of the emitted electrons increases
- Electrons can gain sufficient KE to reach T
- Electrons can leave the surface with greater KE ✓

Photon Model

The photon model predicts no change in the photocurrent
Or photocurrent remains at zero ✓

One from

- The energy of a photon depends on the frequency not the intensity
- Energy of each incident photon remains the same
- KE of electrons leaving the surface does not change
- Electrons released are still unable to reach T ✓

NB The response has to discuss the effect of each theory on the maximum KE of the electrons when they leave the surface

Discussions that relate to threshold frequency or delay before emission are not relevant

3

(c) Fewer electrons will have sufficient energy to move away from the surface/or to reach T/anode
Or
Electrons need more energy to cross the gap
Or
Some of the electrons released were more tightly bound to the surface
Or
Electrons have a range of energies(when emitted from surface)
or
Some electrons use more of the photon energy to escape from the surface (this is related to the energy of the photoelectrons). ✓

Fewer electrons per second have sufficient kinetic energy to reach T scores 2

1

Fewer electrons per second/rate at which electrons reach T will reach terminal T/cross the gap
(the per second part captures what is going on in terms of the current) ✓

Do not allow

Fewer photoelectrons per second flowing through the circuit

1

(d) A > B > C ✓

1

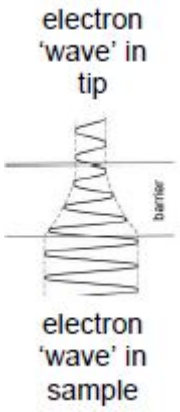
[9]

11. (a) Electrons (in surface) have to overcome the potential/coulomb barrier ✓

Electrons have insufficient energy so (due to wave properties of electrons) there is a probability of electrons crossing from sample to tip
OR
a fraction of electrons will move from sample to tip. ✓

Credit diagram of high amplitude wave, barrier and lower amplitude transmitted wave for second mark

Eg



2

(b) Tip of probe maintained a certain distance (about 1nm) above surface. ✓

(Current from surface into probe due to tunnelling)

When probe moves over higher layer of electrons, current increases ✓

(Through a feedback process) Tip is moved higher to reduce current to original value.
(Distance moved by tip = distance new surface above/below original surface)✓

(Hence surface mapped by position of tip.)

Allow reverse argument

3

(c) Attempt to apply ½ mv^2 = eV

½ x 9.11 x 10^{-31} x v^2 = 2.4 x 10^{-19} ✓

If correct v = 7.26 x 10^5 (m s^{-1})

Allow if no or incorrect conversion of eV to J

Attempt to apply $\lambda = h/mv$

= 6.63 x 10^{-34}/(9.11 x 10^{-31} x 7.26 x 10^5) ✓

Allow for use of their v in substitution

1.0 x 10^{-9} m (cao) with conclusion ✓

Condone 1sf answer, but must have unit

Alternative one step route:

Attempt to put data in $\lambda = \frac{h}{\sqrt{2mE}}$ with no conversion to J ✓

Substitution of data with conversion to J ✓

Answer correct with conclusion ✓

Example conclusion

No - less energy (electron) would have longer wavelength and would be too long to map atom/wavelength should be smaller than 1nm

3

[8]

12. (a)

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$ seen

AND $\mu 0$ ε0 substituted separately from data booklet ✓

To give value of c AND compared with c in booklet ✓

For MP1 condone formula seen AND answer given to at least 5 sf (2.9986 x 10^8 (ms^{-1}))

For MP2 need to see a valid comment that compares calculated value with data booklet value with units to at least 3sf

2

(b) Maxwell's model as varying perpendicular E and B fields (transmitting through space) ✓

(Oscillating) current in T indicates presence of (oscillating) E field ✓

For MP2 allow idea of distribution of charge in T giving rise to electric field

Oscillating current in T produces (horizontal) B field ✓

For MP3 allow moving electrons produces a (varying) magnetic field

Varying (horizontal) B field induces varying emf in loop
OR
Varying (vertical) E field creates a varying emf in loop ✓

For MP4 allow

idea of magnetic field applying force on (moving) charges in the receiver (which is an emf)

OR

Idea of electric field causing change in charge distribution within the loop (which is an emf)

4

(c) In order to determine speed, need to measure wavelength/ distance between nodes OR antinodes in stationary wave ✓

From frequency of 75 MHz and $c = f\lambda$, wavelength = 4 m

For MP3 and MP4 allow for correct calculation leading to idea that three waves will fit between transmitter and detector so YES

OR nodes/antinodes are 2 m apart ✓

Which is less than separation of transmitter and reflector so YES ✓

Answer refers to nodes ✓

In MP3 allow ecf for incorrect wavelength

4

[10]

13. (a) Electromagnetic/EM radiation ✓

Spectrum with peak depending on temperature (of emitter alone). ✓

If no other mark awarded, allow 1 mark for (EM) radiation given off by perfect absorber /emitter.

Condone light for radiation

2

(b) (Description of ultraviolet catastrophe)

If no other mark awarded, 1 mark can be given for idea that there is 'no peak'.

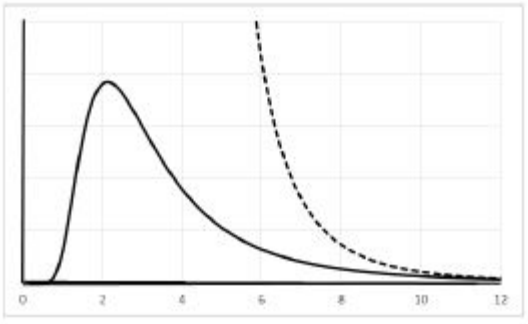
1

Intensity similar at long wavelengths, ✓

(But rather than peak) theory predicts intensity increases at shorter wavelengths/infinite at very short wavelengths✓

Allow correct line on graph for either for 1 mark

But some correct description needed for both



Condone any line that goes to infinity at short wavelengths for MP2.

1

(c) EM radiation emitted in quanta ✓

Energy of quantum is related to a single frequency **OR**

E = hf, where h is Planck's constant. ✓

Do not condone photon or packet for quanta in MP1

2

(d) The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria
6	All 3 areas covered with at least two aspects of photoelectric effect covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all 3 areas. If there are several errors or missing parts then 5 marks should be awarded.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant analysis.

The following statements are likely to be present.

A main outcomes of experiments.

No photoelectric emission if incident light below threshold frequency

Photoelectric emission is instantaneous/occurs as soon as light is incident on metal surface

(Photoelectrons have a range of KE from zero to max value, depending on type of metal and frequency of incident light.

Number of photoelectrons per second is proportional to intensity of incident radiation)

B problems of classical wave theory

Intensity of wave (brightness of light) should determine whether photoelectron emitted/KE of photoelectron OR light of any frequency should cause emission.

Wave energy spread over surface should mean time needed to for electrons to accumulate enough energy to be
emitted/lower intensity the longer the time.

C Aspects of Einstein's theory

Light is made of photons

Photoelectrons due to one photon interacting with one electron in surface of metal.

Minimum energy (work function of metal) needed for electron to be emitted related to a threshold frequency by $\varphi = hf_o$

Remaining energy of photon ($hf-hf_o$) becomes (max) KE of photoelectron.

Brighter source means more photons (per second) and therefore more photoelectrons (per second).

6

[12]