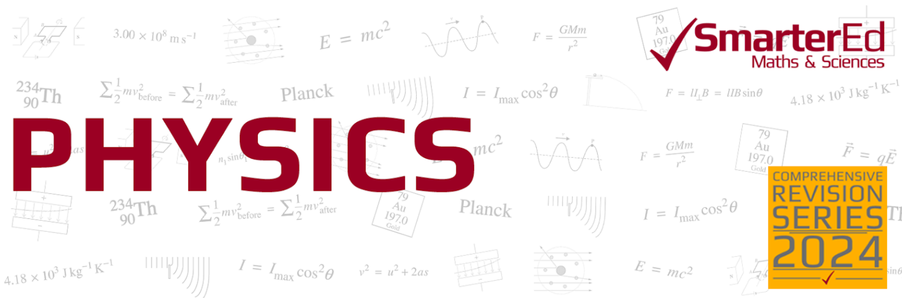


Thank you for subscribing to SmarterScience Teacher Edition in 2024.

Key features of the Physics “2024 HSC Comprehensive Revision Series” for include:

- ~15 hours of cherry picked HSC revision questions by topic
- Targeted at motivated students aiming for a Band 5 or 6 result
- Weighting toward more difficult examples
- Mark allocations given to each topic generally reflect its historical (new syllabus) HSC exam allocation.
- ***Attempt, carefully review and annotate*** this revision set in Term 3
- This question set provides the foundation of a concise and high quality revision resource for the run into the HSC exam.
- This resource should be used to complement (not replace) the critical final stretch preparation for every student - timed full exam practice papers.

Our analysis on each topic, the common question types, past areas of difficulty and recent HSC trends all combine to create this revision set that ensures students cover a wide cross-section of the key areas.

IMPORTANT: If students have been exposed to questions in these worksheets during the year, we say great. Many top performing students attest to the benefits of doing quality questions 2-3 times before the HSC. This type of revision set is aimed at creating confidence and *speed through the exam*, with cherry picked questions that cover all important elements of revision while avoiding low percentage rabbit hole excursions.

HSC Final Study: M7 The Nature of Light

Light: Quantum Model (~9.2% historical contribution)

Key Areas addressed by this worksheet

- The *Quantum Model of Light* is the largest contributor to *M7 The Nature of Light*, appearing in two longer answer questions each new syllabus exam (except for 2022) as well as at least two multiple-choice.
- The *Photoelectric Effect* is the most commonly tested subtopic, attracting a multiple-choice question in each exam of the new syllabus, as well as longer response questions in 2022 and 2019.
- *Experiments* which provide evidence for the quantum model of light have been the subject of regular testing and must be a revision focus (notably absent in 2023). Specific attention should be given to *2021 HSC Q33* which attracted a substantial 9-mark allocation and proved very challenging.
- *Blackbodies* has also been examined frequently, appearing every year of the new syllabus, including two longer answer questions in 2020 with substantial mark allocations. *2020 HSC Q26* caused major problems and is a “must review” question in this area.
- *Kinetic energy calcs* is a concept which has been examined recently in *2021 HSC Q20* and *2022 HSC Q26b.* Challenging revision examples require cross-topic application of formulas to a photoelectric effect scenario.

General study tips:

- *Working past 11 pm while inhaling Red Bull, coffee and chocolate = bad*
- *Getting to bed by 10 pm, waking up at 6 am and studying = good*
- *Extra 10% return – add a cold shower to the mix*

PHYSICS
Stage 6

2024 Comprehensive Revision Series
M7 The Nature of Light
- Light: Quantum Model

Exam Equivalent Time: 90 minutes *(based on allocation of 1.5 minutes per mark)*

Questions

1. PHYSICS, M7 2020 HSC 3 MC

What was the basis for Maxwell's prediction of the velocity of electromagnetic waves?

A. Experiments using magnetic fields to accelerate particles
B. Experiments using light and mirrors to establish the finite speed of light
C. Equations showing how oscillating electric and magnetic fields propagate
D. Equations showing how electromagnetic waves are affected by gravitational fields

---

2. PHYSICS M7 2022 HSC 9 MC

The radiation emitted by a black body has a peak wavelength of 5.8×10^{-7} m.

What is its temperature?

A. 3000 K
B. 4500 K
C. 5000 K
D. 5500 K

---

3. PHYSICS, M7 2016 HSC 13 MC

When light of a specific frequency strikes a metal surface, photoelectrons are emitted.

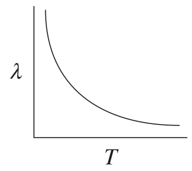
If the light intensity is increased but the frequency remains the same, which row of the table is correct?

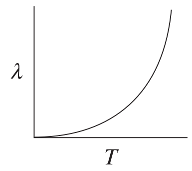
	Number of photoelectrons emitted	*Maximum kinetic energy of the photoelectrons*
(A)	Remains the same	Remains the same
(B)	Remains the same	Increases
(C)	Increases	Remains the same
(D)	Increases	Increases

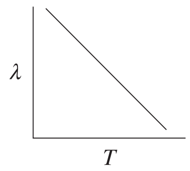
---

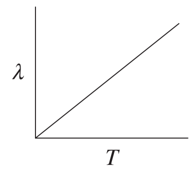
4. PHYSICS, M7 2019 HSC 6 MC

Which graph correctly shows the relationship between the surface temperature of a black body (T) and the wavelength (λ) at which the maximum intensity of light is emitted?

A.


B.


C.


D.


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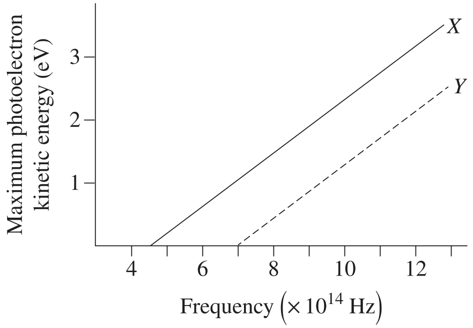
5. PHYSICS, M7 2022 HSC 14 MC

Line X shows the results of an experiment carried out to investigate the photoelectric effect.



What change to this experiment would produce the results shown by line Y ?

A. Increasing the frequency of the radiation

B. Using a metal that has a greater work function

C. Decreasing the intensity of the incident radiation

D. Decreasing the maximum energy of photoelectrons

---

6. PHYSICS, M7 2023 HSC 15 MC

What evidence resulting from investigations into the photoelectric effect is consistent with the model of light subsequently proposed by Einstein?

A. Photoelectrons were only ejected from a metal if the light was less than a specific wavelength.

B. Increasing the intensity of light on a metal increased the maximum kinetic energy of the photoelectrons.

C. If photons had sufficient energy to eject photoelectrons from a metal, the maximum kinetic energy was independent of the type of metal used.

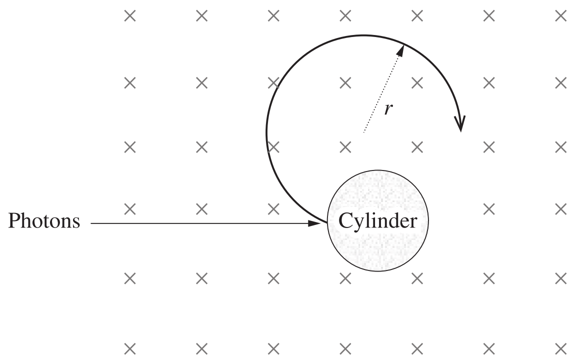
D. The probability of photoelectrons being emitted from a metal was proportional to the duration of exposure to light for any given wavelength used.

---

7. PHYSICS, M7 2021 HSC 20 MC

A metal cylinder is located in a uniform magnetic field. The work function of the metal is ϕ.

Photons having an energy of 2ϕ strike the side of the cylinder, liberating photoelectrons which travel perpendicular to the magnetic field in a circular path. The maximum radius of the path is r.



If the photon energy is doubled, what will the maximum radius of the path become?

A. $2r$

B. $3r$

C. $\sqrt{2}r$

D. $\sqrt{3}r$

---

8. PHYSICS, M7 2017 HSC 21

A laser emits light of wavelength 550 nm.

a. Calculate the frequency of this light. *(2 marks)*

b. The electrons in a specific metal must absorb a minimum of 5×10^{-19} J in order to be ejected from its surface.

Explain why electrons will not be ejected from this metal when photons of wavelength 550 nm strike its surface. Support your answer with relevant calculations. *(3 marks)*

---

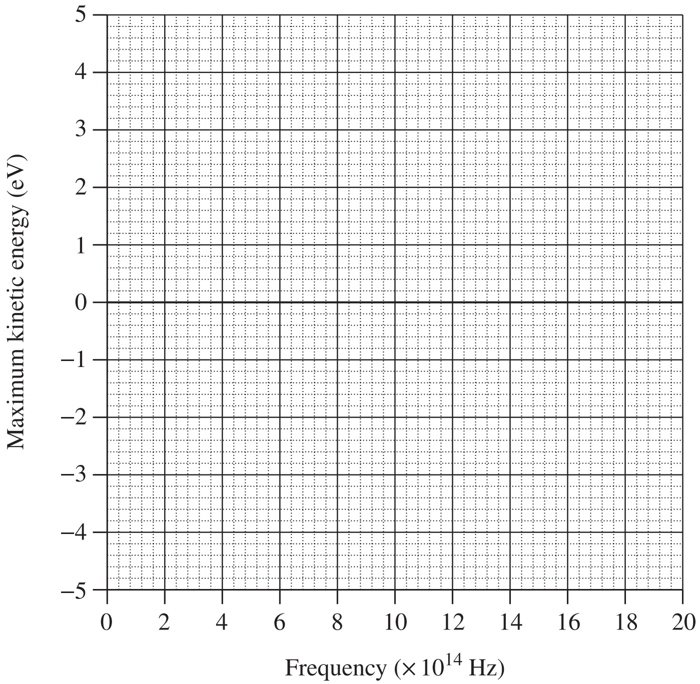
9. PHYSICS, M7 2019 HSC 23

A student investigated the photoelectric effect. The frequency of light incident on a metal surface was varied and the corresponding maximum kinetic energy of the photoelectrons was measured.

The following results were obtained.

Frequency ($\times 10^{14}$ Hz)	11.2	13.5	15.2	18.6	20.0
Maximum kinetic energy (eV)	0.6	1.3	2.3	3.3	4.2

Plot the results on the axes below and hence determine the work function of the metal in electron volts. ***(3 marks)***



10. PHYSICS, M7 2021 VCE 15

A photoelectric experiment is carried out by students. They measure the threshold frequency of light required for photoemission to be 6.5×10^{14} Hz and the work function to be 3.2×10^{-19} J.

Using the students' measurements, what value would they calculate for Planck's constant? Outline your reasoning and show all your working. Give your answer in joule-seconds. ***(3 marks)***

11. PHYSICS, M7 2023 HSC 23b

The James Webb Space Telescope (JWST) is sensitive to wavelengths from 6.0×10^{-7} m to 2.8×10^{-5} m.

What is the minimum photon energy that it can detect? ***(3 marks)***

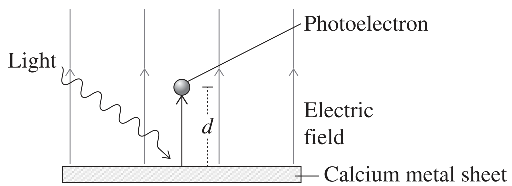
12. PHYSICS, M7 EQ-Bank 32

Applying the law of conservation of energy, explain why $K_{\max} = hf - \phi$. ***(3 marks)***

13. PHYSICS M7 2022 HSC 26

Light of frequency 7.5×10^{14} Hz is incident on a calcium metal sheet which has a work function of 2.9 eV. Photoelectrons are emitted.

The metal is in a uniform electric field of $5.2\ \mathrm{NC}^{-1}$, perpendicular to the surface of the metal, as shown.



a. Show that the maximum kinetic energy of an emitted photoelectron is 3.2×10^{-20} J. ***(3 marks)***

b. Calculate the maximum distance, d, an emitted photoelectron can travel from the surface of the metal. ***(3 marks)***

14. PHYSICS, M7 2020 HSC 22

A capsule travelling at 12 900 m s $^{-1}$ enters Earth's atmosphere, causing it to rapidly slow down to 400 m s $^{-1}$.

a. During this re-entry, the capsule reaches a temperature of 3200 K.

What is the peak wavelength of the light emitted by the capsule? ***(2 marks)***

b. Outline TWO limitations of applying special relativity to the analysis of the motion of the capsule. ***(3 marks)***

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15. PHYSICS, M7 2019 VCE 16

Students are studying the photoelectric effect using the apparatus shown in Figure 15.

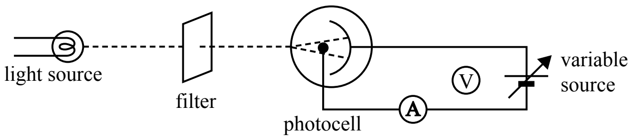


Figure 15

Figure 16 shows the results the students obtained for the maximum kinetic energy ($E_{\mathbf{k\,max}}$) of the emitted photoelectrons versus the frequency of the incoming light.

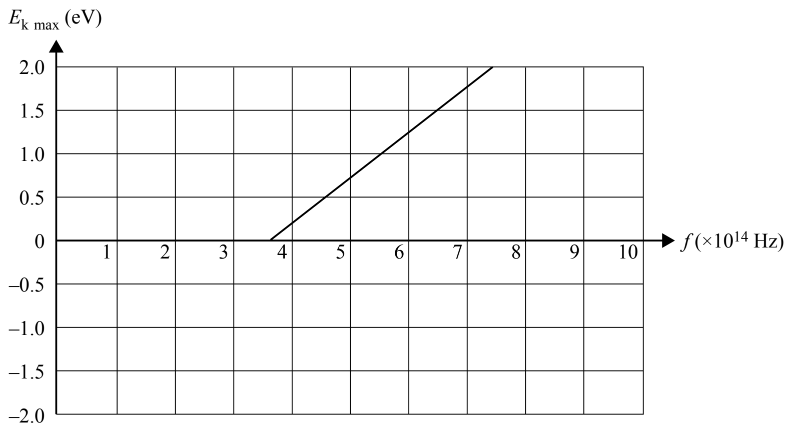


Figure 16

a. Using only data from the graph, determine the values the students would have obtained for

i. Planck's constant, h. Include a unit in your answer ***(2 marks)***

ii. the maximum wavelength of light that would cause the emission of photoelectrons ***(1 mark)***

iii. the work function of the metal of the photocell. ***(1 mark)***

b. The work function for the original metal used in the photocell is ϕ.
On Figure 17, draw the line that would be obtained if a different metal, with a work function of $\frac{1}{2}\phi$, were used in the photocell. The original graph is shown as a dashed line. ***(2 marks)***

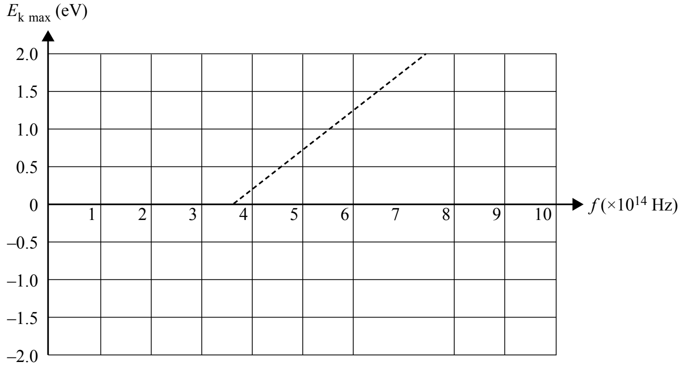
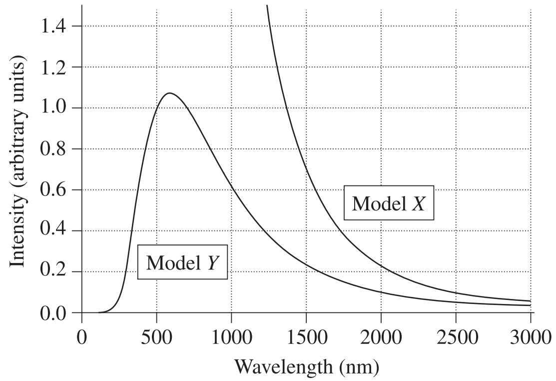


Figure 17

16. PHYSICS, M7 2020 HSC 26

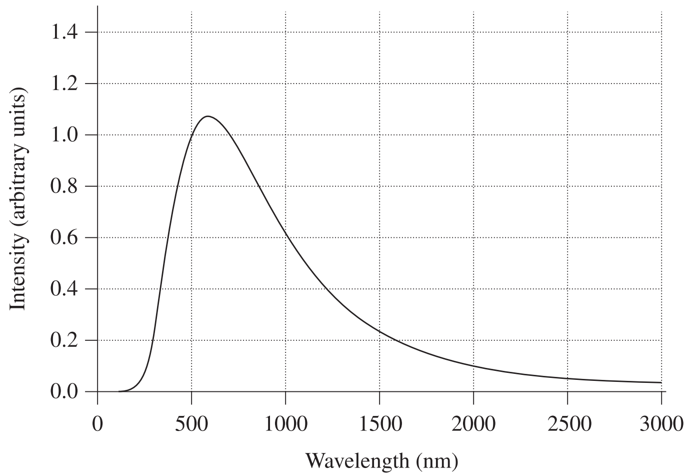
a. Describe the difference between the spectra of the light produced by a gas discharge tube and by an incandescent lamp. ***(2 marks)***

b. The graph shows the curves predicted by two different models, X and Y, for the electromagnetic radiation emitted by an object at a temperature of 5000 K.



Identify an assumption of EACH model which determines the shape of its curve. ***(2 marks)***

c. The diagram shows the radiation curve for a black body radiator at a temperature of 5000 K.



On the same diagram, sketch a curve for a black body radiator at a temperature of 4000 K and explain the differences between the curves. ***(4 marks)***

17. PHYSICS, M7 2021 VCE 16

Light can be described by a wave model and also by a particle (or photon) model. The rapid emission of photoelectrons at very low light intensities supports one of these models but not the other.

Identify the model that is supported, giving a reason for your answer.

---

18. PHYSICS, M8 EQ-Bank 27

Explain how the analysis of quantitative observations contributed to the development of the concept that certain matter and energy are quantised. ***(9 marks)***

Worked Solutions

1. PHYSICS, M7 2020 HSC 3 MC

Maxwell used equations to show interactions between electric and magnetic fields.

$\Rightarrow C$

---

2. PHYSICS M7 2022 HSC 9 MC

$$\lambda_{\text{max}} = \frac{b}{T}$$

$$\begin{aligned} T &= \frac{b}{\lambda_{\text{max}}} \\ &= \frac{2.898 \times 10^{-3}}{5.8 \times 10^{-7}} \\ &\approx 5000 \text{ K} \end{aligned}$$

$\Rightarrow C$

---

3. PHYSICS, M7 2016 HSC 13 MC

→ An increase in light intensity increases the number of photons striking the metal surface.

→ This increases the number of photoelectrons emitted.

→ Since no change in frequency, the energy of photons striking metal surface remains constant.

→ Maximum kinetic energy of emitted photoelectrons remains the same.

$\Rightarrow C$

---

4. PHYSICS, M7 2019 HSC 6 MC

Since $\lambda_{\text{max}} = \dfrac{b}{T}, \quad \lambda \propto \dfrac{1}{T}$ (Wien's Displacement Law)

$\Rightarrow A$

---

5. PHYSICS, M7 2022 HSC 14 MC

→ The work function of the metals is given by the respective *y*-intercepts of lines X and Y.

→ As line Y has a *y*-intercept with greater magnitude, it can be produced by using a metal with a greater work function.

$\Rightarrow B$

---

6. PHYSICS, M7 2023 HSC 15 MC

♦ Mean mark 46%.

→ A photoelectron will be ejected from a metal if the energy of the photoelectron transferred from the photon is greater than the work function of the metal surface where

$$K_{\max} = hf - \phi \quad \Rightarrow \quad K_{\max} = \frac{hc}{\lambda} - \phi$$

→ By decreasing the wavelength of the light, the maximum kinetic energy of the photoelectron increases, thus it has enough energy to overcome the work function of the metal and be ejected from the surface of the metal.

→ Increasing the intensity of the light increases the number of photons but has no effect on the maximum kinetic energy of the photoelectrons.

$\Rightarrow A$

---

7. PHYSICS, M7 2021 HSC 20 MC

♦ Mean mark 24%.

$$K_{\max} = \frac{1}{2}mv_{\max}^2$$

$$v_{\max} = \sqrt{\frac{2K_{\max}}{m}} \quad \ldots (1)$$

$$r = \frac{mv}{qB}$$

Substitute into (1):

$$r = \frac{m}{qB}\sqrt{\frac{2K_{\max}}{m}}$$

$$r \propto \sqrt{K_{\max}}$$

When the photon energy is 2ϕ, $K_{\max} = \phi$.

When the photon energy is doubled to 4ϕ, $K_{\max} = 3\phi$.

$\therefore$ As $r \propto \sqrt{K_{\max}}$ the radius increases by a factor of $\sqrt{3}$.

$\Rightarrow D$

---

8. PHYSICS, M7 2017 HSC 21

a.

$$v = f\lambda$$

$$f = \frac{v}{\lambda} = \frac{3 \times 10^8}{550 \times 10^{-9}} = 5.45 \times 10^{14}\ \text{Hz}$$

b.

$$E = hf = 6.62 \times 10^{-34} \times 5.46 \times 10^{14} = 3.63 \times 10^{-19}\ \text{J}$$

→ The work function of the metal sample is 5×10^{-19} J.

→ Since the incident photon energy of 3.63×10^{-19} J is less than 5×10^{-19} J, they are unable to eject electrons from the metal.

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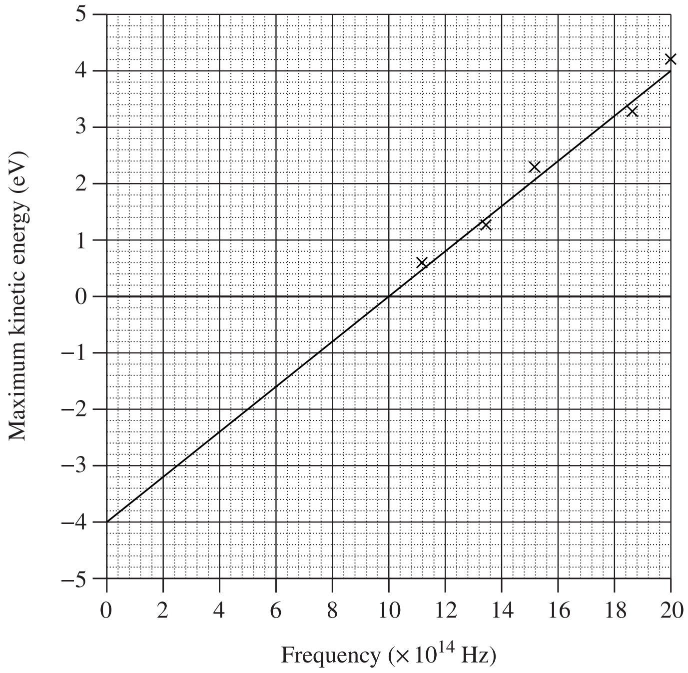
9. PHYSICS, M7 2019 HSC 23



The metal has a work function of 4 eV (this is the negative of the y-intercept).

10. PHYSICS, M7 2021 VCE 15

$$f = 6.5 \times 10^{14}\ \text{Hz}, \quad E = 3.2 \times 10^{-19}\ \text{J}$$

$$E = hf \quad \Rightarrow \quad h = \frac{E}{f}$$

$$\therefore h = \frac{3.2 \times 10^{-19}}{6.5 \times 10^{14}} = 4.92 \times 10^{-34}\ \text{J s}$$

11. PHYSICS, M7 2023 HSC 23b

→ The minimum photon energy corresponds to the minimum frequency.

→ Minimum frequency occurs at the maximum wavelength as frequency and wavelength are inversely proportional.

$$\begin{aligned} E_{\text{min}} &= hf \\ &= \frac{hc}{\lambda} \\ &= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{2.8 \times 10^{-5}} \\ &= 7.1 \times 10^{-21}\ \text{J} \end{aligned}$$

12. PHYSICS, M7 EQ-Bank 32

→ The law of conservation of energy states that energy cannot be created or destroyed, only transferred or transformed into different forms.

→ The initial energy of a photon is equal to hf.

→ If this photon strikes a metal surface, a photoelectron may be released. Some energy is required to remove the electron from the metal surface which is equal to the work function (ϕ) of the metal.

→ The electron will also possess kinetic energy, K_{max}.

→ Applying the law of conservation of energy, the energy before equals the energy after, or $hf = K_{\text{max}} + \phi$.

→ Rearranging this gives $K_{\text{max}} = hf - \phi$.

13. PHYSICS M7 2022 HSC 26

a. $K_{\max} = hf - \Phi$

$= 6.626 \times 10^{-34} \times 7.5 \times 10^{14} - 2.9 \times 1.602 \times 10^{-19}$

$= 3.2 \times 10^{-20}$ J

b. Maximum Distance:

→ The electric field will do 3.2×10^{-20} J of work to stop the electron.

♦ Mean mark (b) 51%.

$$W = qEd$$

$$3.2 \times 10^{-20} = 1.602 \times 10^{-19} \times 5.2 \times d_{\max}$$

$$\therefore d_{\max} = \frac{3.2 \times 10^{-20}}{1.602 \times 10^{-19} \times 5.2}$$

$$= 0.038 \text{ m.}$$

---

14. PHYSICS, M7 2020 HSC 22

a. $\lambda_{\max} = \dfrac{b}{T}$

$$= \frac{2.898 \times 10^{-3}}{3200}$$

$$= 9.056 \times 10^{-7} \text{ m}$$

$$= 9 \times 10^{-7} \text{ m}$$

b. Limitations:

→ The speed of the capsule is not close to the speed of light and so the effects of special relativity are insignificant.

♦ Mean mark (b) 42%.

→ The capsule is decelerating and so it is in a non-inertial frame of reference, therefore special relativity is not applicable.

---

15. PHYSICS, M7 2019 VCE 16

a.i. Planck's constant (h):

→ Equal to the gradient of the line when $E_{\text{k max}}$ is graphed against frequency.

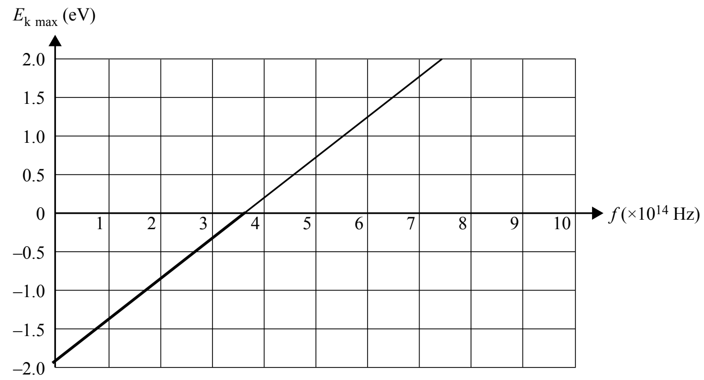
$$\therefore h = \frac{\text{rise}}{\text{run}} = \frac{1.25 - 0}{6 \times 10^{14} - 3.7 \times 10^{-14}} = 5.4 \times 10^{-15} \text{ eV s}$$

a.ii. → Max wavelength = minimum frequency of emitted photoelectron.

♦ Mean mark (a)(ii) 44%.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^{8}}{3.7 \times 10^{14}} = 811 \text{ nm}$$

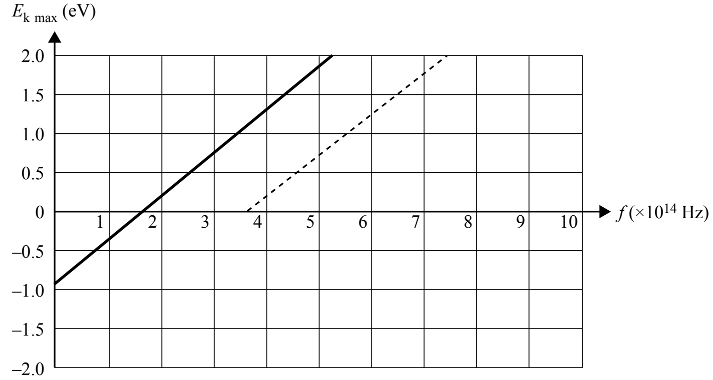
a.iii.



→ The work function is the y-intercept of the graph, so by extending the graph as shown above, the work function is 1.9 eV.

b. → The new y-intercept for the graph will be -0.95 eV

→ The gradient of the graph will remain the same (Planck's constant)



16. PHYSICS, M7 2020 HSC 26

a. Differences:

→ The spectra of light produced by a gas discharge tube will consist of lines only at a few discrete wavelengths.
→ The spectra of light produced by an incandescent lamp will be a continuous spectrum.

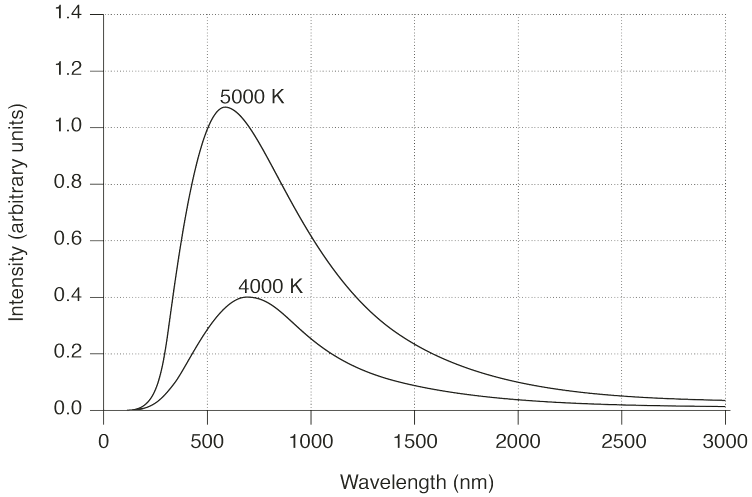
♦ Mean mark (a) 39%.

b. Assumptions of EACH model:

→ Model X black bodies absorb and emit energy continuously.
→ Model Y assumes that black bodies absorb and emit energy in discrete quantities.

♦ Mean mark (b) 44%.

c.



Using $\lambda_{max} = \dfrac{b}{T} \quad \Rightarrow \quad \lambda \propto \dfrac{1}{T}$
Therefore, the 4000 K curve will have a peak wavelength greater than the 5000 K curve. The area under the curve and the intensity at all wavelengths will be less for the 4000 K curve, as the total power output of a black body decreases as its temperature decreases.

17. PHYSICS, M7 2021 VCE 16

→ Model supported: Particle (photon) model

♦ Mean mark 42%.

Reasons could include one of the following:

→ Each electron ejection corresponds to the absorption of a single photon.

→ The immediate ejection of a photoelectron corresponds to its direct interaction with the initial photon.

→ Contrary to the wave theory, which suggests that energy accumulates gradually, the emission of photoelectrons at very low light intensities demonstrates that energy is delivered in discrete quanta.

18. PHYSICS, M8 EQ-Bank 27

Experiments such as Millikan's oil drop experiment and others testing the photoelectric effect have demonstrated that certain quantities of matter and energy are quantised which means they are multiples of some fundamental value.

Millikan's Oil Drop Experiment

→ Millikan's oil drop experiment was able to show that charge is quantised.

→ Millikan levitated oil drops in an electric field by balancing the electric and gravitational forces on them. This allowed him to find the electric force acting on each oil drop, and using the mass of the oil drop he found its charge.

→ Analysing his results, he found that the charge on every oil drop was an integer multiple of $1.602 \times 10^{-19} C$. This was determined to be the fundamental charge on an electron.

→ Further, with Thompson's later discovery of the charge to mass ratio of an electron, its mass could be determined.

Photoelectric Effect

→ Photoelectric effect experiments showed the quantum properties of light which seemingly contradicted the view of light as a wave.

→ It was found that there was a minimum frequency (energy) of light that would cause photoemission when it was incident upon a metal plate, and no photoemission occurred with light lower than this frequency, regardless of intensity.

→ As one photon would strike one electron on the metal surface, the electron would receive a discrete amount of energy from that photon determined by its frequency $E = hf$. If a photon didn't have enough energy, an electron couldn't be removed.

→ This experimental evidence changed the conceptual understanding of energy within physics and provided a basis for the quantisation of the energy of light.

Other quantitative experiments that could be explored include:

→ Bohr's analysis of emission spectra to demonstrate the existence of quantised energy levels in atoms.

→ Cathode ray experiments showing the particle nature of electrons.

→ Blackbody radiation experiments.