Week 26

AP Physics 2

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Physics 2 Name: ____________________ Score: ________

1. The energy of a single photon is given by:
   - ☐ $E = mc^2$
   - ☐ $E = hf$
   - ☐ $E = \frac{1}{2}mv^2$
   - ☐ $E = IV$
2. In the Bohr model, an electron can have:
   - ☐ any energy at all
   - ☐ only certain fixed energy levels
   - ☐ zero energy always
   - ☐ negative frequency
3. An emission spectrum shows:
   - ☐ dark lines on a rainbow
   - ☐ bright lines on a black background
   - ☐ a smooth rainbow only
   - ☐ nothing
4. As a blackbody gets hotter, its peak wavelength:
   - ☐ gets longer (redder)
   - ☐ gets shorter (bluer)
   - ☐ stays the same
   - ☐ disappears
5. Below the threshold frequency, increasing the brightness of the light:
   - ☐ ejects many electrons
   - ☐ ejects no electrons at all
   - ☐ ejects faster electrons
   - ☐ melts the metal
6. A photon is only absorbed if its energy exactly matches the gap between two levels.

   ☐ True ☐ False

7. For a given element, its absorption lines fall at the same frequencies as its emission lines.

   ☐ True ☐ False

8. A hotter blackbody emits more intensity at every wavelength than a cooler one.

   ☐ True ☐ False

9. Above the threshold, higher-frequency light ejects electrons with more kinetic energy.

   ☐ True ☐ False

10. Nuclear fusion powers the ______ and the stars.

    ____

AP Physics 2

1. $E = hf$

   $E = hf$ — Planck's constant times the frequency.

2. **only certain fixed energy levels**

   Energy levels are quantised — only certain fixed values are allowed.

3. **bright lines on a black background**

   Electrons dropping down emit photons, giving bright lines on black.

4. **gets shorter (bluer)**

   A hotter body peaks at a shorter wavelength — the glow shifts toward blue.

5. **ejects no electrons at all**

   Below threshold, each photon is too weak — brightness cannot free any electrons.

6. **True**

   Only photons matching a level gap can be absorbed or emitted.

7. **True**

   Both come from the same energy-level gaps, so they share the same frequencies.

8. **True**

   The hotter curve is taller at all wavelengths.

9. **True**

   $hf = \phi + \mathrm{KE}_{\mathrm{max}}$: more photon energy leaves more kinetic energy.

10. **Sun**

    The Sun fuses hydrogen into helium, releasing its energy.

AP PHYSICS 2 • EXERCISE SHEET

15.1 Quantum Theory and Wave-Particle Duality

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS photon 光子 • de broglie wavelength 德布罗意波长 • wave-particle duality 波粒二象性 • quanta 量子

Objective

Build the skills to answer exam questions on **quantum theory and wave-particle duality**.

You must be able to:

- describe a **photon** 光子 as a quantum of light with energy $E = hf$
- explain **wave-particle duality** 波粒二象性: light and matter show both behaviours
- relate a particle's momentum to its **de Broglie wavelength** 德布罗意波长 $\lambda = h/p$

1 Worked examples

Study these first. Each one shows the method for a question type used later.

The photon

Light is delivered in quanta called **photons**, each with energy $E = hf$, where $h = 6.63 \times 10^{-34}$ J s.

Wave-particle duality

Light and matter each show **wave** behaviour (interference, diffraction) and **particle** behaviour (photons, collisions), depending on the experiment.

De Broglie wavelength

Every particle has a wavelength $\lambda = \dfrac{h}{p}$.

2 Practice

2.1 Find the energy of a photon of frequency 6.0×10^{14} Hz ($h = 6.63 \times 10^{-34}$). [2]

2.2 State the equation for the de Broglie wavelength. [1]

2.3 State what "wave-particle duality" means. [1]

---

3 Exam-style questions

3.1 The energy of a photon is [1]

- **A** hf
- **B** h/f
- **C** hp
- **D** $\frac{1}{2}mv^2$

3.2 The de Broglie wavelength of a particle is [1]

- **A** hp
- **B** h/p
- **C** p/h
- **D** hf

3.3 A photon has a wavelength of 500 nm ($c = 3.0 \times 10^8$, $h = 6.63 \times 10^{-34}$).

(a) Find its frequency. [2]

(b) Find its energy. [2]

Solutions

2.1 $E = hf = (6.63 \times 10^{-34})(6.0 \times 10^{14}) = 4.0 \times 10^{-19}$ J.

2.2 $\lambda = \dfrac{h}{p}$.

2.3 that light and matter each behave both as waves and as particles.

3.1 **A**.

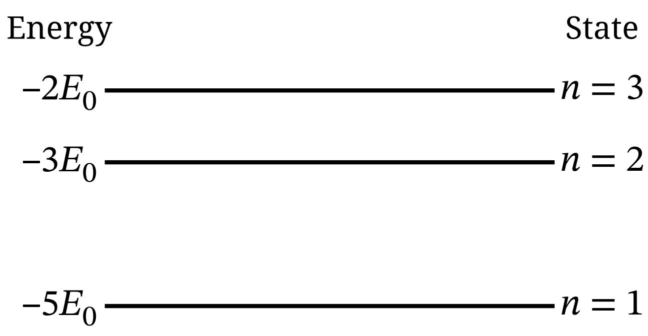
3.2 **B**.

3.3 (a) $f = \dfrac{c}{\lambda} = \dfrac{3.0 \times 10^{8}}{500 \times 10^{-9}} = 6.0 \times 10^{14}$ Hz. (b) $E = hf = (6.63 \times 10^{-34})(6.0 \times 10^{14}) = 4.0 \times 10^{-19}$ J.

Question 2: Version J

2. Figure 1 represents the energy levels and their corresponding states for a hypothetical atom.

Figure 1



Part A

On Figure 1, **draw** arrows to represent all possible atomic transitions that could result in the emission of a photon.

Part B

Derive an expression for the wavelength of the highest-energy photon that can be emitted from the atom. Express your answer in terms of E_0 and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

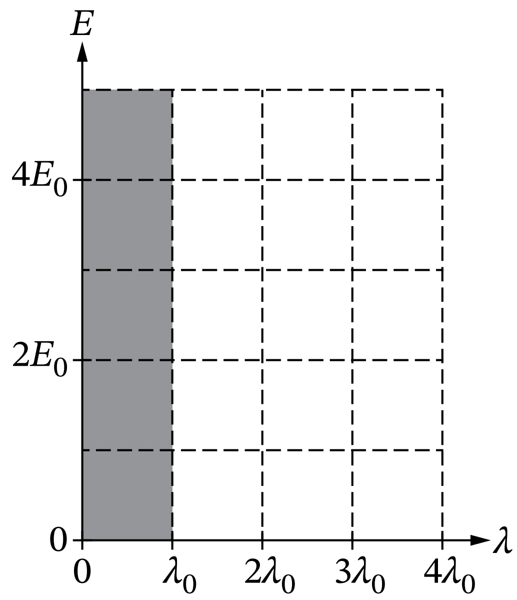
The following information applies to parts C and D.

A device can emit monochromatic electromagnetic radiation. The wavelength λ of the radiation can be varied over a continuous range of wavelengths.

Part C

On Figure 2, **sketch** the energy E of emitted photons from the device as a function of λ for $\lambda_0 < \lambda < 4\lambda_0$. Photons with wavelength λ_0 have energy $4E_0$. Sketches made in the shaded region will not be scored.

Figure 2



Part D

A student claims that, based on the energy states shown in Figure 1, the atom can emit a photon of wavelength λ_0 and energy $4E_0$ like the device described in part C.

Indicate whether the claim is correct or incorrect. Briefly **justify** your answer by referencing the representation in part A.

Begin your response to **QUESTION 1** on this page.

PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)

In each trial of a photoelectric experiment, a scientist uses a device to shine light of a single frequency on two different metals, 1 and 2. The device can emit light with frequency f_A, f_B, or f_C. Each frequency of light is used to test both metals.

The scientist determines the minimum de Broglie wavelength λ_e of the electrons ejected from the metal in each trial of the experiment. The following table summarizes the results of the experiment. For each trial, the scientist analyzes only the electrons with the minimum de Broglie wavelength.

Trial	Frequency of Light	Metal Tested	λ_e ($\times 10^{-10}$ m)
1	f_A	Metal 1	6.9
2	f_A	Metal 2	9.4
3	f_B	Metal 1	No electrons ejected
4	f_B	Metal 2	No electrons ejected
5	f_C	Metal 1	5.3
6	f_C	Metal 2	6.3

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

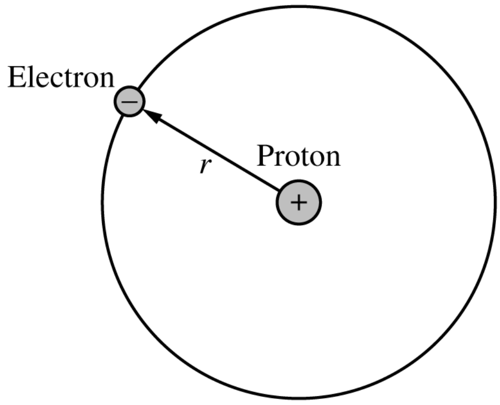
(a) In a coherent, paragraph-length response, **indicate** which frequency, f_A, f_B, or f_C, is greatest and which frequency is least. **Justify** your answer using physics principles.

(b) **Calculate** the maximum kinetic energy of the electrons ejected from Metal 1 in Trial 1. Assume that the momentum p of an ejected electron can be described by the classical definition $p = mv$.

(c) **Indicate** whether the work function of Metal 1 is greater than, less than, or equal to the work function of Metal 2. **Justify** your answer by referring to the table of results.

GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 3** on this page.



Note: Figure not drawn to scale.

. (12 points, suggested time 25 minutes)

A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

(b) Derive an equation for the total energy of the atom in terms of r and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) When the hydrogen atom absorbs a photon, the electron moves to an orbit with a larger radius and the total energy of the atom increases. Is your equation for the energy derived in part (b) consistent with this description of the model of a hydrogen atom absorbing a photon? Explain why the equation is or is not consistent.

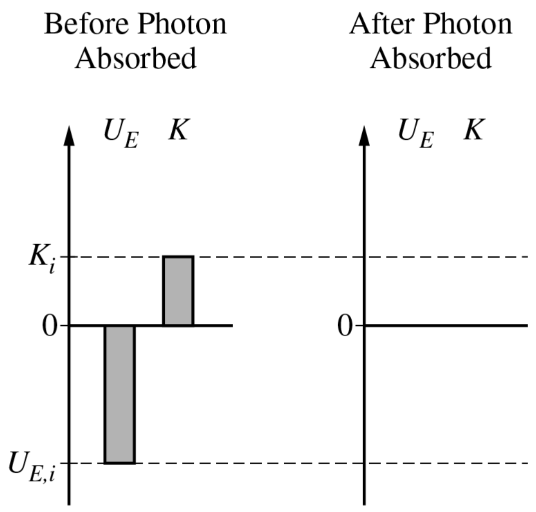
(d) Experiments show that a hydrogen atom can absorb a photon of frequency 3.2×10^{15} Hz.

i. Calculate the energy of a photon with this frequency.

ii. A student claims that when a hydrogen atom absorbs a photon at this frequency, the energy could be converted into mass, adding an electron to the atom. Calculate the amount of energy needed to create a particle with the mass of an electron and determine whether or not there is sufficient energy gained by the atom to add another electron.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



iii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,\,i}$ of the atom and the initial kinetic energy K_i of the electron before the photon is absorbed. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 4** on this page.

4. (10 points, suggested time 20 minutes)

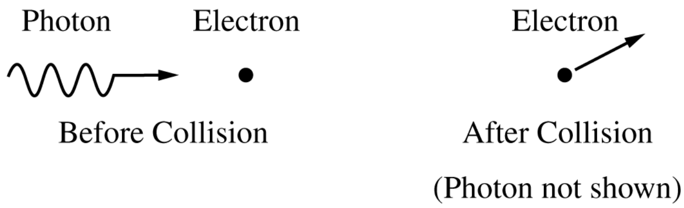
Light and matter can be modeled as waves or as particles. Some phenomena can be explained using the wave model, and others can be explained using the particle model.

(a) Calculate the speed, in m/s, of an electron that has a wavelength of 5.0 nm.

(b) The electron is moving with the speed calculated in part (a) when it collides with a positron that is at rest. A positron is a particle identical to an electron except that its charge is positive. The two particles annihilate each other, producing photons. Calculate the total energy of the photons.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.



(c) A photon approaches an electron at rest, as shown above on the left, and collides elastically with the electron. After the collision, the electron moves toward the top of the page and to the right, as shown above on the right, at a known speed and angle. In a coherent, paragraph-length response, indicate a possible direction for the photon that exists after the collision and its frequency compared to that of the original photon. Describe the application of physics principles that can be used to determine the direction of motion and frequency of the photon that exists after the collision.

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

AP PHYSICS 2 • EXERCISE SHEET

15.2 The Bohr Model of Atomic Structure

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS energy levels 能级 • bohr model 玻尔模型 • photons 光子

Objective

Build the skills to answer exam questions on **the Bohr model of atomic structure**.

You must be able to:

- describe the **Bohr model 玻尔模型** with electrons in discrete, quantized **energy levels 能级**
- explain that an electron absorbs or emits a photon when it changes level
- relate the photon energy to the difference between levels, $E = hf = E_i - E_f$

1 Worked examples

Study these first. Each one shows the method for a question type used later.

The Bohr model

Electrons occupy only certain **discrete** energy levels — their energy is **quantized**, not continuous.

Photons and level changes

An electron **absorbs** a photon to jump up a level and **emits** a photon when it drops down.

Photon energy

$E = hf = E_i - E_f$ — the photon carries exactly the energy difference between the two levels.

2 Practice

2.1 State what is meant by quantized energy levels. [1]

2.2 State what happens when an electron drops to a lower energy level. [1]

2.3 An electron falls from a level at -1.5 eV to one at -3.4 eV. Find the energy of the emitted photon. [2]

3 Exam-style questions

3.1 In the Bohr model, the electron energy levels are [1]

- **A** continuous
- **B** quantized
- **C** all zero
- **D** infinite

3.2 An electron emits a photon when it [1]

- **A** stays in a level
- **B** moves to a higher level
- **C** moves to a lower level
- **D** leaves the atom

3.3 An electron drops from a level at -0.85 eV to one at -3.4 eV.

(a) Find the energy of the photon, in eV. [2]

(b) State whether the photon is absorbed or emitted. [1]

Solutions

2.1 the electron can only have certain allowed energy values, not any value in between.

2.2 it emits a photon carrying the energy difference.

2.3 $E = E_i - E_f = (-1.5) - (-3.4) = 1.9$ eV.

3.1 **B**.

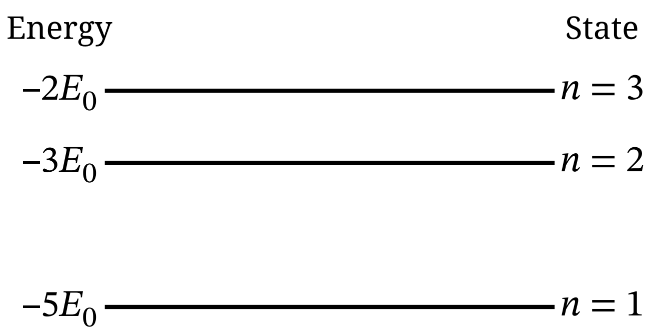
3.2 **C**.

3.3 (a) $E = (-0.85) - (-3.4) = 2.55$ eV. (b) emitted (the electron drops to a lower level).

Question 2: Version J

2. Figure 1 represents the energy levels and their corresponding states for a hypothetical atom.

Figure 1



Part A

On Figure 1, **draw** arrows to represent all possible atomic transitions that could result in the emission of a photon.

Part B

Derive an expression for the wavelength of the highest-energy photon that can be emitted from the atom. Express your answer in terms of E_0 and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

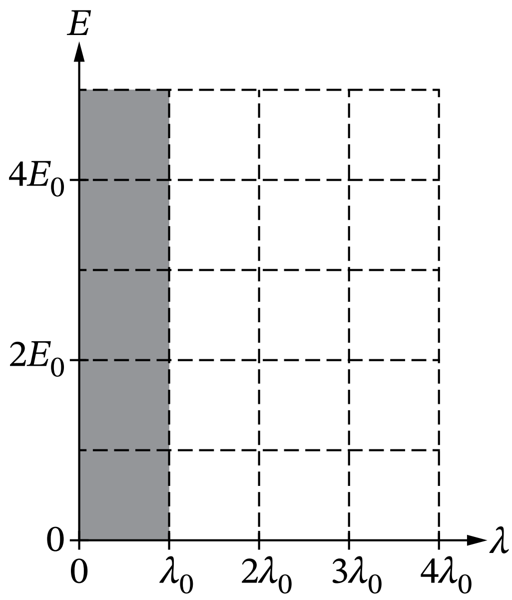
The following information applies to parts C and D.

A device can emit monochromatic electromagnetic radiation. The wavelength λ of the radiation can be varied over a continuous range of wavelengths.

Part C

On Figure 2, **sketch** the energy E of emitted photons from the device as a function of λ for $\lambda_0 < \lambda < 4\lambda_0$. Photons with wavelength λ_0 have energy $4E_0$. Sketches made in the shaded region will not be scored.

Figure 2

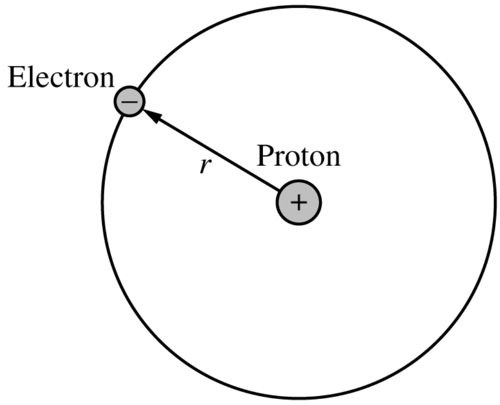


Part D

A student claims that, based on the energy states shown in Figure 1, the atom can emit a photon of wavelength λ_0 and energy $4E_0$ like the device described in part C.

Indicate whether the claim is correct or incorrect. Briefly **justify** your answer by referencing the representation in part A.

Begin your response to **QUESTION 3** on this page.



Note: Figure not drawn to scale.

. (12 points, suggested time 25 minutes)

A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

(b) Derive an equation for the total energy of the atom in terms of r and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) When the hydrogen atom absorbs a photon, the electron moves to an orbit with a larger radius and the total energy of the atom increases. Is your equation for the energy derived in part (b) consistent with this description of the model of a hydrogen atom absorbing a photon? Explain why the equation is or is not consistent.

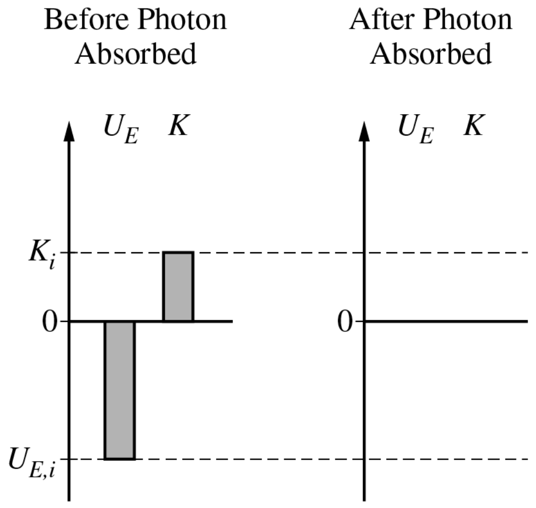
(d) Experiments show that a hydrogen atom can absorb a photon of frequency 3.2×10^{15} Hz.

i. Calculate the energy of a photon with this frequency.

ii. A student claims that when a hydrogen atom absorbs a photon at this frequency, the energy could be converted into mass, adding an electron to the atom. Calculate the amount of energy needed to create a particle with the mass of an electron and determine whether or not there is sufficient energy gained by the atom to add another electron.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



iii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,i}$ of the atom and the initial kinetic energy K_i of the electron before the photon is absorbed. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.

(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

15.3 Emission and Absorption Spectra

Name: ______________ Class: _________ Date: ____________ **Total: 10 marks**

KEY WORDS emission 发射 • absorption 吸收 • absorption spectrum 吸收光谱 • emission spectrum 发射光谱 • energy levels 能级

Objective

Build the skills to answer exam questions on **emission and absorption spectra**.

You must be able to:

- explain how discrete energy levels produce line **emission 发射** and **absorption 吸收** spectra
- relate each spectral line to a specific electron transition
- describe how spectra identify the elements in a gas or a star

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Line spectra

Because energy levels are **discrete**, an atom emits or absorbs only certain photon energies — giving sharp **lines**, not a continuous band.

Emission vs absorption

- **Emission** — bright lines from photons **released** as electrons drop down.
- **Absorption** — dark lines where photons are **absorbed** to lift electrons up.

A fingerprint

Each element has a unique set of lines, so spectra identify the elements in a gas or star.

2 Practice

2.1 Explain why atoms produce line spectra rather than continuous ones. [2]

2.2 State the difference between an emission and an absorption spectrum. [2]

2.3 State how a spectrum can identify an element. [1]

3 Exam-style questions

3.1 Line spectra are evidence that atomic energy levels are [1]

- **A** continuous
- **B** quantized
- **C** all zero
- **D** random

3.2 A spectrum of dark lines on a bright background is produced by [1]

- **A** emission
- **B** absorption
- **C** reflection
- **D** diffraction

3.3 The light from a star shows dark lines that match those of hydrogen.

(a) Name this type of spectrum. [1]

(b) State what it tells us about the star. [2]

Solutions

2.1 the energy levels are discrete, so only certain photon energies (and wavelengths) can be emitted or absorbed.

2.2 an emission spectrum is bright lines from emitted photons; an absorption spectrum is dark lines where photons are absorbed.

2.3 each element has a unique pattern of lines.

3.1 **B**.

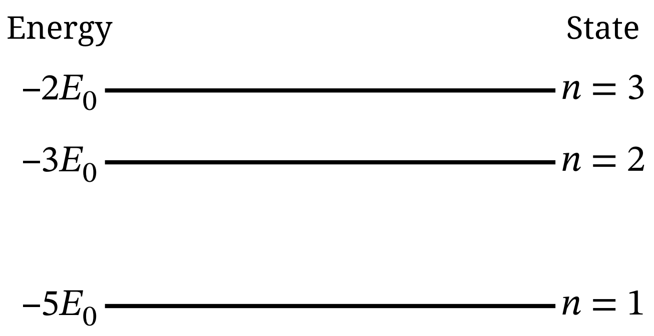
3.2 **B**.

3.3 (a) an absorption spectrum. (b) hydrogen is present in the star's outer layers, absorbing those wavelengths.

Question 2: Version J

2. Figure 1 represents the energy levels and their corresponding states for a hypothetical atom.

Figure 1



Part A

On Figure 1, **draw** arrows to represent all possible atomic transitions that could result in the emission of a photon.

Part B

Derive an expression for the wavelength of the highest-energy photon that can be emitted from the atom. Express your answer in terms of E_0 and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

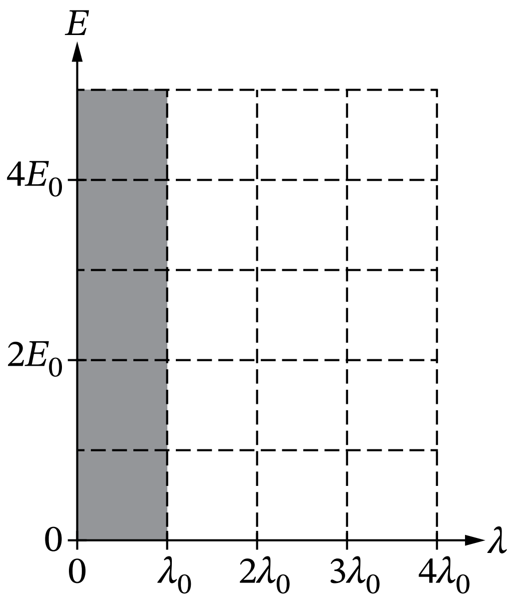
The following information applies to parts C and D.

A device can emit monochromatic electromagnetic radiation. The wavelength λ of the radiation can be varied over a continuous range of wavelengths.

Part C

On Figure 2, **sketch** the energy E of emitted photons from the device as a function of λ for $\lambda_0 < \lambda < 4\lambda_0$. Photons with wavelength λ_0 have energy $4E_0$. Sketches made in the shaded region will not be scored.

Figure 2

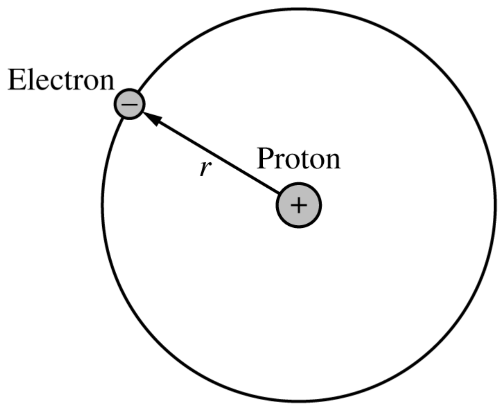


Part D

A student claims that, based on the energy states shown in Figure 1, the atom can emit a photon of wavelength λ_0 and energy $4E_0$ like the device described in part C.

Indicate whether the claim is correct or incorrect. Briefly **justify** your answer by referencing the representation in part A.

Begin your response to **QUESTION 3** on this page.



Note: Figure not drawn to scale.

. (12 points, suggested time 25 minutes)

A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

(b) Derive an equation for the total energy of the atom in terms of r and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) When the hydrogen atom absorbs a photon, the electron moves to an orbit with a larger radius and the total energy of the atom increases. Is your equation for the energy derived in part (b) consistent with this description of the model of a hydrogen atom absorbing a photon? Explain why the equation is or is not consistent.

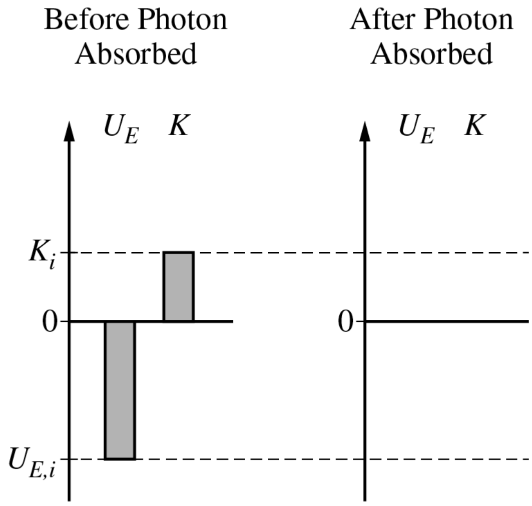
(d) Experiments show that a hydrogen atom can absorb a photon of frequency 3.2×10^{15} Hz.

i. Calculate the energy of a photon with this frequency.

ii. A student claims that when a hydrogen atom absorbs a photon at this frequency, the energy could be converted into mass, adding an electron to the atom. Calculate the amount of energy needed to create a particle with the mass of an electron and determine whether or not there is sufficient energy gained by the atom to add another electron.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



iii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,\,i}$ of the atom and the initial kinetic energy K_i of the electron before the photon is absorbed. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.

(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

15.4 Blackbody Radiation

Name: ____________ Class: ________ Date: __________ **Total: 8 marks**

KEY WORDS blackbody 黑体 • wien’s law 维恩定律 • energy quantization 能量量子化 • quanta 量子

Objective

Build the skills to answer exam questions on **blackbody radiation**.

You must be able to:

- describe the continuous spectrum emitted by a hot **blackbody 黑体**
- state that the peak wavelength shifts shorter as temperature rises (**Wien’s law 维恩定律**)
- explain how blackbody radiation motivated the idea of **energy quantization 能量量子化**

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ A blackbody

A hot object emits a **continuous** spectrum of all wavelengths, with a peak that depends on temperature.

■ Wien’s law

The **peak wavelength gets shorter** as the temperature rises — so a hotter object glows from red toward blue-white.

■ Why it mattered

Classical physics could not explain the blackbody curve; Planck fixed it by proposing that energy comes in **quanta** — the start of quantum theory.

2 Practice

2.1 State what happens to the peak wavelength of a blackbody as it gets hotter. [1]

2.2 State the type of spectrum emitted by a hot solid. [1]

2.3 State why blackbody radiation was historically important. [1]

3 Exam-style questions

3.1 As a blackbody gets hotter, its peak wavelength [1]

- **A** increases
- **B** decreases
- **C** stays the same
- **D** disappears

3.2 A hotter star appears more [1]

- **A** red
- **B** blue
- **C** green
- **D** infrared

3.3 Star A glows red and star B glows blue-white.

(a) State which star is hotter. [1]

(b) Explain your answer using the idea of peak wavelength. [2]

Solutions

2.1 it gets shorter.

2.2 a continuous spectrum.

2.3 it could not be explained by classical physics and led to the idea of energy quanta.

3.1 B.

3.2 B.

3.3 (a) star B (blue-white). (b) a shorter peak wavelength (bluer) means a higher temperature, by Wien's law.

AP PHYSICS 2 • EXERCISE SHEET

15.5 The Photoelectric Effect

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS work function 功函数 • photoelectric effect 光电效应 • threshold frequency 截止频率 • photons 光子

Objective

Build the skills to answer exam questions on **the photoelectric effect**.

You must be able to:

- describe the **photoelectric effect 光电效应**: light ejecting electrons from a metal
- apply the photoelectric equation $E = hf = \phi + KE_{max}$ with the **work function 功函数** ϕ
- explain why a **threshold frequency 截止频率** exists

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ The photoelectric effect

Light shining on a metal can eject electrons, but only if each **photon** carries enough energy.

■ The photoelectric equation

$hf = \phi + KE_{max}$, where ϕ (the work function) is the minimum energy to free an electron, and KE_{max} is the most kinetic energy an ejected electron can have.

■ Threshold frequency

Below a threshold frequency f_0 (where $hf_0 = \phi$), **no** electrons are emitted, however bright the light — direct evidence that light is quantized.

2 Practice

2.1 State what the photoelectric effect is. [1]

2.2 Define the work function of a metal. [1]

2.3 A metal has a work function of 2.0 eV. A photon of 5.0 eV strikes it. Find the maximum kinetic energy of the ejected electron. [2]

3 Exam-style questions

3.1 The photoelectric equation is [1]

- **A** $hf = \phi + KE_{max}$
- **B** $E = mc^2$
- **C** $E = \frac{1}{2}mv^2$
- **D** $\lambda = h/p$

3.2 Below the threshold frequency, the number of electrons emitted is [1]

- **A** at its maximum
- **B** zero
- **C** half the usual
- **D** steadily increasing

3.3 Light of photon energy 4.0 eV strikes a metal of work function 2.5 eV.

(a) Find the maximum kinetic energy of an ejected electron. [2]

(b) Explain why even very dim light of this frequency still ejects electrons. [2]

Solutions

2.1 light ejecting electrons from the surface of a metal.

2.2 the minimum energy needed to free an electron from the metal.

2.3 $KE_{max} = hf - \phi = 5.0 - 2.0 = 3.0$ eV.

3.1 **A**.

3.2 **B**.

3.3 (a) $KE_{max} = 4.0 - 2.5 = 1.5$ eV. (b) each photon has enough energy on its own to free an electron, so even a few photons (dim light) eject some — brightness only changes how many.

Begin your response to **QUESTION 1** on this page.

PHYSICS 2

SECTION II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

1. (10 points, suggested time 20 minutes)

In each trial of a photoelectric experiment, a scientist uses a device to shine light of a single frequency on two different metals, 1 and 2. The device can emit light with frequency f_A, f_B, or f_C. Each frequency of light is used to test both metals.

The scientist determines the minimum de Broglie wavelength λ_e of the electrons ejected from the metal in each trial of the experiment. The following table summarizes the results of the experiment. For each trial, the scientist analyzes only the electrons with the minimum de Broglie wavelength.

Trial	Frequency of Light	Metal Tested	λ_e ($\times 10^{-10}$ m)
1	f_A	Metal 1	6.9
2	f_A	Metal 2	9.4
3	f_B	Metal 1	No electrons ejected
4	f_B	Metal 2	No electrons ejected
5	f_C	Metal 1	5.3
6	f_C	Metal 2	6.3

GO ON TO THE NEXT PAGE.

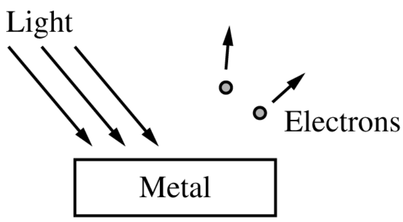
Continue your response to **QUESTION 1** on this page.

(a) In a coherent, paragraph-length response, **indicate** which frequency, f_A, f_B, or f_C, is greatest and which frequency is least. **Justify** your answer using physics principles.

(b) **Calculate** the maximum kinetic energy of the electrons ejected from Metal 1 in Trial 1. Assume that the momentum p of an ejected electron can be described by the classical definition $p = mv$.

(c) **Indicate** whether the work function of Metal 1 is greater than, less than, or equal to the work function of Metal 2. **Justify** your answer by referring to the table of results.

GO ON TO THE NEXT PAGE.

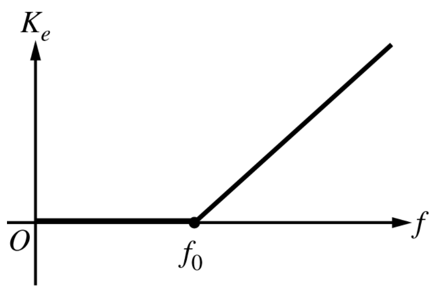


3. (12 points, suggested time 25 minutes)

Monochromatic light of frequency f shines on a metal, as shown above. The frequency of the light is varied, and for some frequencies electrons are emitted from the metal. The maximum kinetic energy K_e of the emitted electrons is measured as a function of the frequency of the light.

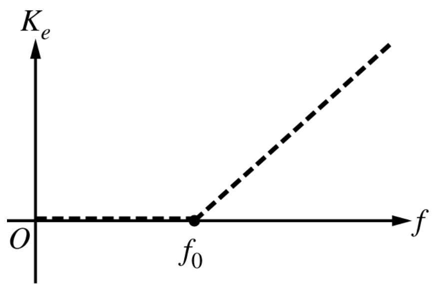
(a)

i. Based on conservation of energy, the relationship between K_e and f is predicted to be $Af = B + K_e$ when $f > f_0$ and $K_e = 0$ when $f \le f_0$, where A and B are positive constants. A graph of this relationship is shown below. Indicate which aspects of the graph correspond to A and B. Also, explain the physical meaning of A, B, and f_0.

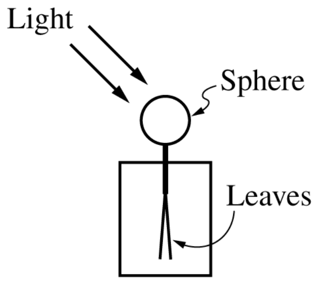


ii. Explain the physical meaning of the horizontal section of the graph between the origin and f_0.

iii. A second metal with different properties than the first metal is now used. On the figure below, the dashed lines are the same lines shown in the previous graph. Sketch lines on the figure below that could represent the data for the second metal. Explain one difference between the two graphs.



(b) The figure below shows an electroscope. A sphere is connected by a vertical bar to the leaves, which are thin, light strips of material. The sphere, leaves, and bar are all made of metal. The electroscope initially has a negative charge, so the leaves are separated.



i. Ultraviolet (UV) light shines on the sphere, causing the leaves of the electroscope to move closer together. Explain why this happens.

ii. Green light then shines on an identical negatively charged electroscope. No movement of the leaves is observed. Explain why the green light does not make the leaves move, while the UV light does.

(c) The brightness of the green light is increased until the intensity (power per unit area) is the same as that of the UV light. What aspect of the green light changes when its brightness is increased? Would shining the brighter green light on the electroscope result in movement of the leaves? Explain why or why not.

15.6 Compton Scattering

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS compton scattering 康普顿散射 • momentum 动量

Objective

Build the skills to answer exam questions on **Compton scattering**.

You must be able to:

- describe **Compton scattering 康普顿散射** as a photon colliding with an electron
- explain that the scattered photon has a longer wavelength (lower energy)
- state that Compton scattering conserves both energy and **momentum 动量**

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Compton scattering

A photon collides with an electron much like two particles — clear evidence of the **particle** nature of light.

■ Wavelength shift

The photon gives some energy to the electron, so the **scattered photon has less energy** and therefore a **longer wavelength**.

■ Conservation

Both **energy** and **momentum** are conserved in the collision.

2 Practice

2.1 State what Compton scattering involves. [1]

2.2 State what happens to the photon's wavelength after scattering. [1]

2.3 State the two quantities conserved in Compton scattering. [2]

3 Exam-style questions

3.1 In Compton scattering, the scattered photon has a [1]

- **A** shorter wavelength
- **B** longer wavelength
- **C** higher frequency
- **D** unchanged energy

3.2 Compton scattering treats light as a [1]

- **A** wave
- **B** particle
- **C** field
- **D** fluid

3.3 A photon scatters off a stationary electron.

(a) State what happens to the photon's energy. [1]

(b) Explain your answer using conservation of energy. [2]

Solutions

2.1 a photon colliding with an electron.

2.2 it increases (the wavelength gets longer).

2.3 energy and momentum.

3.1 **B**.

3.2 **B**.

3.3 (a) it decreases. (b) the photon transfers some energy to the electron; by conservation of energy the photon is left with less, so its frequency falls and wavelength grows.

Begin your response to **QUESTION 4** on this page.

4. (10 points, suggested time 20 minutes)

Light and matter can be modeled as waves or as particles. Some phenomena can be explained using the wave model, and others can be explained using the particle model.

(a) Calculate the speed, in m/s, of an electron that has a wavelength of 5.0 nm.

(b) The electron is moving with the speed calculated in part (a) when it collides with a positron that is at rest. A positron is a particle identical to an electron except that its charge is positive. The two particles annihilate each other, producing photons. Calculate the total energy of the photons.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

Before Collision

After Collision

(Photon not shown)

(c) A photon approaches an electron at rest, as shown above on the left, and collides elastically with the electron. After the collision, the electron moves toward the top of the page and to the right, as shown above on the right, at a known speed and angle. In a coherent, paragraph-length response, indicate a possible direction for the photon that exists after the collision and its frequency compared to that of the original photon. Describe the application of physics principles that can be used to determine the direction of motion and frequency of the photon that exists after the collision.

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

15.7 Fission, Fusion, and Nuclear Decay

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS mass 质量 • fission 裂变 • fusion 聚变 • half-life 半衰期 • radioactive decay 放射性衰变

Objective

Build the skills to answer exam questions on **fission, fusion, and nuclear decay**.

You must be able to:

- distinguish nuclear **fission** 裂变 (splitting) from **fusion** 聚变 (joining)
- relate the energy released to a change in **mass** 质量, $E = mc^2$
- describe **radioactive decay** 放射性衰变 as a random process with a **half-life** 半衰期

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Fission and fusion

- **Fission** — a heavy nucleus splits into lighter ones.
- **Fusion** — light nuclei join into a heavier one (as in the Sun).

Both release energy from a loss of mass.

Mass-energy

$E = mc^2$: a tiny mass change gives a huge energy, because c^2 is enormous.

Decay and half-life

Radioactive decay is **random** — you cannot predict when a given nucleus decays. The **half-life** is the time for half the nuclei to decay.

2 Practice

2.1 State the difference between nuclear fission and fusion. [2]

2.2 State what the half-life of a radioactive substance means. [1]

2.3 A mass of 2.0×10^{-3} kg is converted entirely to energy ($c = 3.0 \times 10^{8}$). Find the energy released. [2]

3 Exam-style questions

3.1 Joining two light nuclei into a heavier one is called [1]

- **A** fission
- **B** fusion
- **C** decay
- **D** ionization

3.2 The energy released in a nuclear reaction comes from a change in [1]

- **A** charge
- **B** mass
- **C** volume
- **D** temperature

3.3 A radioactive sample has a half-life of 8 days, starting with 80 g.

(a) Find the mass remaining after 16 days. [2]

(b) Explain why radioactive decay is described as random. [1]

Solutions

2.1 fission is the splitting of a heavy nucleus; fusion is the joining of light nuclei.

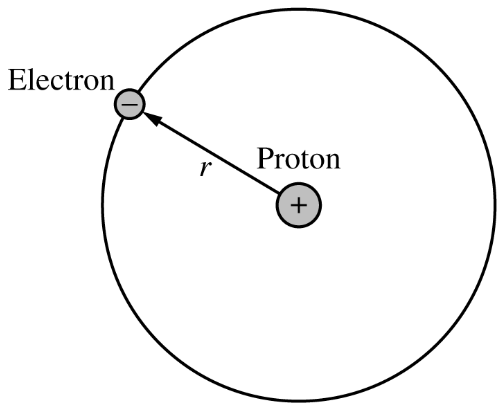
2.2 the time taken for half of the radioactive nuclei to decay.

2.3 $E = mc^2 = (2.0 \times 10^{-3})(3.0 \times 10^8)^2 = 1.8 \times 10^{14}$ J.

3.1 **B**.

3.2 **B**.

3.3 (a) after two half-lives: $80 \to 40 \to 20$ g. (b) you cannot predict which nucleus will decay or when — only the probability.



<u>Note:</u> Figure not drawn to scale.

. (12 points, suggested time 25 minutes)

A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

(b) Derive an equation for the total energy of the atom in terms of r and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) When the hydrogen atom absorbs a photon, the electron moves to an orbit with a larger radius and the total energy of the atom increases. Is your equation for the energy derived in part (b) consistent with this description of the model of a hydrogen atom absorbing a photon? Explain why the equation is or is not consistent.

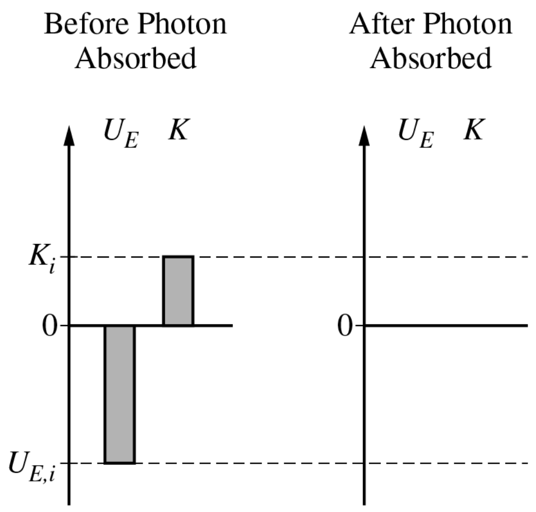
(d) Experiments show that a hydrogen atom can absorb a photon of frequency 3.2×10^{15} Hz.

i. Calculate the energy of a photon with this frequency.

ii. A student claims that when a hydrogen atom absorbs a photon at this frequency, the energy could be converted into mass, adding an electron to the atom. Calculate the amount of energy needed to create a particle with the mass of an electron and determine whether or not there is sufficient energy gained by the atom to add another electron.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



iii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,\,i}$ of the atom and the initial kinetic energy K_i of the electron before the photon is absorbed. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

GO ON TO THE NEXT PAGE.

15.8 Types of Radioactive Decay

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS alpha 阿尔法 • gamma 伽马 • beta 贝塔 • alpha decay 阿尔法衰变 • gamma decay 伽马衰变

Objective

Build the skills to answer exam questions on **types of radioactive decay**.

You must be able to:

- describe **alpha 阿尔法**, **beta 贝塔**, and **gamma 伽马** decay and what each emits
- write balanced nuclear equations that conserve nucleon number and charge
- compare the penetrating power of the three types

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ The three decays

- **Alpha** — emits a helium nucleus ($^{4}_{2}$He).
- **Beta** — emits a fast electron.
- **Gamma** — emits a high-energy photon (electromagnetic wave).

■ Balanced nuclear equations

Both the **nucleon number** (top) and the **charge** (bottom) must balance on each side.

■ Penetrating power

Alpha is the **least** penetrating (stopped by paper); beta is stopped by aluminium; **gamma is the most** penetrating (needs thick lead).

2 Practice

2.1 State what is emitted in alpha, beta, and gamma decay. [2]

2.2 State which type of radiation is the most penetrating. [1]

2.3 In alpha decay, state how the mass number and the atomic number change. [2]

3 Exam-style questions

3.1 An alpha particle is a [1]

- **A** helium nucleus
- **B** fast-moving electron
- **C** high-energy photon
- **D** single proton

3.2 The most penetrating type of radiation is [1]

- **A** alpha
- **B** beta
- **C** gamma
- **D** all equally penetrating

3.3 A nucleus $^{238}_{92}\mathrm{U}$ emits an alpha particle.

(a) State the mass number of the new nucleus. [1]

(b) State its atomic number. [1]

(c) Name the two quantities that must be conserved in the equation. [1]

Solutions

2.1 alpha: a helium nucleus; beta: a fast electron; gamma: a high-energy photon.

2.2 gamma.

2.3 the mass number decreases by 4 and the atomic number decreases by 2.

3.1 **A**.

3.2 **C**.

3.3 (a) $238 - 4 = 234$. (b) $92 - 2 = 90$. (c) nucleon number and charge.