دليل مراجعة وإتقان مع الحلول (محلول)

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إعداد: Alwardat Mohammed

التواصل الاجتماعي بحسب الصف الثاني عشر المتقدم

صفحة المناهج الإماراتية على فيسبوك

المواد على تلغرام | التربية الاسلامية | اللغة العربية | اللغة الانجليزية | الرياضيات

المزيد من الملفات بحسب الصف الثاني عشر المتقدم والمادة فيزياء في الفصل الأول

1	دليل مراجعة وإتقان مع الحلول (محلول)
2	هيكل مراجعة
3	هيكل امتحان نهاية الفصل
4	ملزمة شرح وتدريبات القوى الكهروستاتيكية – الوحدة الأولى
5	ملزمة مراجعة عامة وأسئلة تدريبية محلولة لامتحان نهاية الفصل

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GRADE 12 ADVANCED · PHYSICS TERM 1 (2026–2027)

Teacher Copy · Complete Solutions

Physics Revision & Mastery Guide

Topic Primers · Dual-Coded Visuals · Step-by-Step Worked Examples & Practice

Prepared by: Mohammed Alwardat · 0568779171

Student Name: _____ Class / Section: _____ Date: _____

16 Multiple Choice Q1–Q16 (2–4 pts)	**4** Free Response Q17–Q20 (8–11 pts)	**100** Total Score Calculator Allowed	**150** Minutes Electronic & Paper

5-UNIT STUDY ROADMAP (GROUPED BY CONCEPT)

01 **Work, Potential Energy & Conservation**
Q1, Q2 (MCQ) + FRQ Q17 · Module 10 (pp. 14–28, 32)

02 **Collisions, Momentum & Kinetic Energy**
Q3 (MCQ) + FRQ Q18 · Module 10 (pp. 29–32)

03 **Thermal Radiation, Photons & Photoelectric**
Q4–Q8 (MCQ) + FRQ Q19 · Module 22 (pp. 46–58)

04 **Wave–Particle Duality, Compton & Uncertainty**
Q9–Q11 (MCQ) · Module 22 (pp. 57–61)

05 **Atomic Models, Spectra, Bohr Atom & Lasers**
Q12–Q16 (MCQ) + FRQ Q20 · Module 22 (pp. 62–79)

CORE EQUATIONS QUICK-REFERENCE

Unit / Topic	Essential Formulas
Energy & Work	$GPE = mgh$; $W_g = -\Delta GPE$; $KE_{trans} = \frac{1}{2}mv^2$; $KE_{rot} = \frac{1}{2}I\omega^2$; $E_0 = mc^2$
Collisions	$p_{Ai} + p_{Bi} = p_{Af} + p_{Bf}$; Elastic: $KE_f = KE_i$; Inelastic: $KE_f < KE_i$
Photons & Photoelectric	$E = nhf = \frac{hc}{\lambda} = \frac{1240\ \text{eV·nm}}{\lambda}$; $KE_{max} = hf - W = eV_0$
Duality & Bohr Atom	$p = \frac{h}{\lambda}$; $\lambda = \frac{h}{mv}$; $E_n = \frac{-13.6\ \text{eV}}{n^2}$; $E_{photon} = \lvert E_i - E_f \rvert$

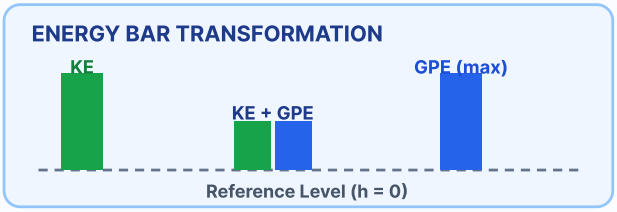
UNIT 1 · Q1, Q2 · FRQ Q17

Work, Potential Energy & Conservation of Mechanical Energy

Royal Blue · Module 10 (pp. 14–28, 32)

TOPIC PRIMER · CONCEPT GUIDE Energy, Work & Conservation (Module 10)

Big Idea: Energy cannot be created or destroyed—it only transforms between **kinetic energy** (motion), **gravitational potential energy** (height), and **elastic potential energy** (stretched/compressed springs). Setting a convenient **reference level** ($h = 0$) simplifies every problem because only *changes* in height matter.



WORK DONE BY GRAVITY (W_g)

- Moving UP: F_g (↓) opposes d (↑) → $W_g = -mgh$
- Moving DOWN: F_g (↓) aligns d (↓) → $W_g = +mgh$

Always: $W_g = -\Delta GPE$

Quantity / Law	Formula	Units & Meaning
Gravitational Potential Energy	$GPE = mgh$	J (joules); $g = 9.8$ m/s^2
Work Done by Gravity	$W_g = -\Delta GPE = -mg(h_f - h_i)$	Negative going up, positive going down
Translational & Rotational KE	$KE_{trans} = \frac{1}{2}mv^2$; $KE_{rot} = \frac{1}{2}I\omega^2$	Both contribute to rolling objects
Rest Energy (Mass–Energy)	$E_0 = mc^2$	$c = 3.00 \times 10^8$ m/s
Conservation of Mechanical Energy	$KE_i + PE_i = KE_f + PE_f$	Valid when no friction / external work acts

Watch Out (Common Trap): Work done by **you** lifting at constant speed is **+mgh**, whereas work done by **gravity** during the same lift is **−mgh**! Also, if friction acts, $ME_f < ME_i$ because energy turns into thermal energy.

Q1	MCQ OBJECTIVE **Define potential energy & GPE (*GPE = mgh*), relate gravitational work to −Δ*GPE*, and trace vertical energy transformations.**	pp. 14–20, 22, 25 E.P(4) · P.P(31–34) · Get it 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q1 (GPE & Work by Gravity) — rising in difficulty

1 **A 4.0-kg backpack is lifted 1.5 m onto a table. Relative to the floor, its gravitational potential energy is:**

A 6.0 J

B 39.2 J

C 58.8 J

D 118 J

Answer: C — $GPE = mgh = 4.0 \times 9.8 \times 1.5 =$ **58.8 J**.

2 **As a ball is thrown straight upward, the work done by gravity on the ball is:**

A positive, increasing its kinetic energy

B negative, decreasing its kinetic energy

C zero, because gravity is conservative

D positive, because height increases

Answer: B — Gravity pulls downward while displacement is upward, so W_g is **negative** and slows the ball.

3 **A 2.5-kg stone is dropped from a 12-m cliff. At a height of 4.0 m above the ground, the work done by gravity so far is:**

A +98 J

B −196 J

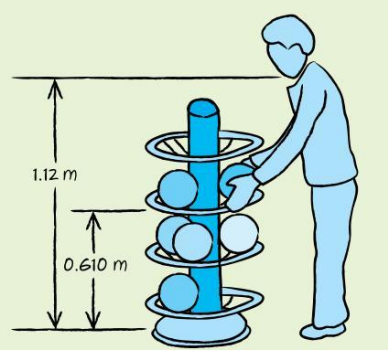
C +196 J

D +294 J

Answer: C — Drop distance $\Delta h = 12 - 4.0 = 8.0$ m → $W_g = +mg\Delta h = 2.5 \times 9.8 \times 8.0 =$ **+196 J**.

EXAMPLE PROBLEM 4 Student Book p. 19

You lift a 7.30-kg bowling ball from a storage rack (0.610 m above the floor) to your shoulder (1.12 m above the floor). Find: **a.** GPE relative to the floor, **b.** GPE relative to the rack, **c.** work done by gravity.



Given	m = 7.30 kg, h_{rack} = 0.610 m, $h_{shoulder}$ = 1.12 m
Step 1	**Part (a): Relative to floor (h = 1.12 m):** $GPE = mgh = 7.30 \times 9.8 \times 1.12 =$ **80.1 J**
Step 2	**Part (b): Relative to rack (Δh = 1.12 − 0.610 = 0.51 m):** $GPE = 7.30 \times 9.8 \times 0.51 =$ **36.5 J**
Step 3	**Part (c): Work done by gravity:** $W_g = -\Delta GPE = -36.5$ J = **−36.5 J**
Answer	**a) 80.1 J | b) 36.5 J | c) −36.5 J**

PRACTICE PROBLEM 31 Student Book p. 20

If you slowly lower a 20.0-kg bag of sand 1.20 m from the trunk of a car to the driveway, how much work do you do?

Given	m = 20.0 kg, d = 1.20 m downward; Your upward holding force $F_{you} = mg$ opposes downward displacement (θ = 180°).
Step 1	**Calculate work done by you:** $W_{you} = -mgd = -(20.0)(9.8)(1.20) =$ **−235 J**
Answer	**W_{you} = −235 J**

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PRACTICE PROBLEM 32 Student Book p. 20

A boy lifts a 2.2-kg book from his desk (0.80 m high) to a bookshelf (2.10 m high). Find the GPE of the book–Earth system relative to the desk.

Given	m = 2.2 kg, Δh = 2.10 − 0.80 = 1.30 m above desk
Step 1	**Calculate GPE relative to desk:** $GPE = mg\Delta h$ = 2.2 × 9.8 × 1.30 = **28 J** (28.0 J)
Answer	***GPE* = 28 J**

PRACTICE PROBLEM 33 Student Book p. 20

A 1.8-kg brick falls to the ground from a chimney 6.7 m high. What is the change in GPE of the brick–Earth system?

Given	m = 1.8 kg, h_i = 6.7 m, h_f = 0
Step 1	**Calculate ΔGPE:** $\Delta GPE = mg(h_f - h_i)$ = 1.8 × 9.8 × (0 − 6.7) = **-1.2×10^2 J** (−118 J)
Answer	**$\Delta GPE = -1.2 \times 10^2$ J**

PRACTICE PROBLEM 34 (CHALLENGE) Student Book p. 20

A worker lifts a 10.1-kg box onto a 1.1-m table, slides it 5.0 m along the table, and lowers it back to the floor (ignore friction). Find the changes in energy and total change.

Given	m = 10.1 kg, h = 1.1 m
Step 1	**1. Lifting to table:** ΔGPE = +10.1 × 9.8 × 1.1 = **+109 J**
Step 2	**2. Sliding horizontally & lowering back:** Sliding: ΔGPE = 0; Lowering: ΔGPE = **−109 J** → Net change = **0 J**
Answer	**+109 J (up), 0 J (across), −109 J (down); Total change = 0 J**

GET IT? Student Book p. 25

1. How would the ball's final kinetic energy in Figure 23 differ if friction transformed some energy?
2. In a bouncing ball, where does the rest of the kinetic energy go?

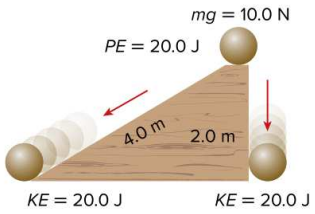


Figure 23 If friction does no work on the ball, the ball's final kinetic energy is equal to its initial gravitational potential energy regardless of which path it follows.

Given	Energy conservation with non-conservative forces
Step 1	**Question 1:** Final kinetic energy would be **less than 20.0 J** because friction transforms mechanical energy into thermal energy.
Step 2	**Question 2:** The remaining energy transforms into **thermal energy and sound** inside the ball and floor.
Answer	**1) Less than 20.0 J | 2) Thermal energy and sound**

Q2 | **MCQ OBJECTIVE**

Define elastic potential energy, interpret mass as rest energy ($E_0 = mc^2$), and identify other forms of energy.

pp. 20–22 · S.T.B C.Y.P(35) · Get it 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q2 (Elastic PE & Rest Energy) — rising in difficulty

1 **Energy stored in a compressed spring or stretched bowstring due to a change in shape is called:**

A translational kinetic energy
B elastic potential energy
C gravitational potential energy
D rest energy

Answer: B — Stored energy due to deformation of an elastic object is **elastic potential energy**.

2 **According to Einstein's equation $E_0 = mc^2$, a tiny mass of 2.0×10^{-6} kg corresponds to a rest energy of:**

A 6.0×10^{2} J
B 1.8×10^{11} J
C 9.0×10^{10} J
D 3.6×10^{11} J

Answer: B — $E_0 = (2.0 \times 10^{-6})(3.00 \times 10^{8})^2 = \mathbf{1.8 \times 10^{11}\ J}$.

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3 **A pole-vaulter runs, plants a flexible fiberglass pole, and rises 5.5 m over the bar. Which energy sequence is correct?**

A GPE → KE → Elastic PE	**B** **KE → Elastic PE → GPE**
C Elastic PE → Thermal → KE	**D** Rest energy → KE → GPE

Answer: B — Running (**KE**) bends the pole (**Elastic PE**), which straightens and lifts the vaulter (**GPE**).

CHECK YOUR PROGRESS 35 Student Book p. 22

You compress the spring in a jumping toy, then release it so it flies straight up. Describe the energy bars (for the toy + Earth system) at: **a.** compressed, **b.** spring expands & toy jumps, **c.** top of flight.

Given	System = jumping toy + Earth (no friction)
Step 1	**a) Pushed down:** 100% **Elastic PE** (KE = 0, GPE = 0)
Step 2	**b) Spring expands & jumps:** Mostly **Kinetic Energy (KE)** + small GPE (Elastic PE = 0)
Step 3	**c) Top of flight:** 100% **Gravitational PE (GPE)** (KE = 0, Elastic PE = 0)
Answer	**a) Elastic PE → b) KE (+ small GPE) → c) GPE**

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FRQ Q17

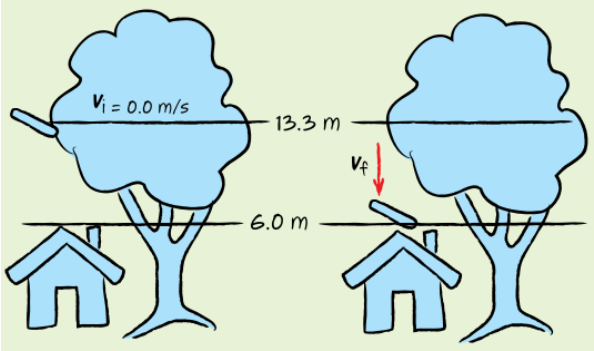
FRQ · FREE RESPONSE

Calculate translational & rotational KE, gravitational work, and apply conservation of mechanical energy.

pp. 19, 23–28, 32
E.P(4,5) · P.P(39–43)
C.Y.P(47,50,51) · 8–11 marks

EXAMPLE PROBLEM 5 **FRQ · FREE RESPONSE** Student Book p. 27

A 22.0-kg tree limb is 13.3 m above the ground and falls onto a roof 6.0 m above the ground (no air resistance). Find: **a.** kinetic energy at the roof, and **b.** speed at the roof.



Given m = 22.0 kg, h_i = 13.3 m, h_f = 6.0 m, v_i = 0

Initial Energy (ME_i) ①

~~KE_i~~ + GPE_i

$ME_i = 0 + mg\,h_i$

Final Energy (ME_f) ②

$KE_f + GPE_f$

$ME_f = KE_f + mg\,h_f$

Step 1 **Part (a): Solve Eq. 1 = Eq. 2 for KE_f:** $KE_f = mg(h_i - h_f) = 22.0 \times 9.8 \times (13.3 - 6.0) =$ **1.57×10^3 J**

Step 2 **Part (b): Solve for speed v_f:** $v_f = \sqrt{\dfrac{2\,KE_f}{m}} = \sqrt{\dfrac{2 \times 1573.9}{22.0}} =$ **12.0 m/s**

Answer **a) 1.57×10^3 J (1.6×10^3 J) | b) 12.0 m/s**

PRACTICE PROBLEMS 39 & 40 **FRQ · FREE RESPONSE** Student Book p. 28

39. A bike + rider (85.0 kg) coast up a hill from 8.5 m/s without friction. Find initial KE and stopping height.
40. If the rider pedals up instead and never stops, in what system is energy conserved and from what energy did the bike gain ME?

Given	$m = 85.0$ kg, $v_i = 8.5$ m/s, $v_f = 0$
Step 1	**39: Initial KE:** $KE_i = \frac{1}{2}mv_i^2 = \frac{1}{2}(85.0)(8.5)^2 =$ **3.1×10^3 J** (3071 J)
Step 2	**39: Stopping height:** $mgh_f = KE_i \rightarrow h_f = \frac{3070.6}{85.0 \times 9.8} =$ **3.7 m**
Step 3	**40: Energy source:** Conserved in the **bike + rider + Earth** system; mechanical energy came from **chemical energy** in the rider's muscles.
Answer	**39) 3.1×10^3 J, 3.7 m | 40) Bike+rider+Earth; chemical energy**

PRACTICE PROBLEM 41 **FRQ · FREE RESPONSE** Student Book p. 28

A skier starts from rest at the top of a 45.0-m hill (30° incline), skis into a valley, and climbs a 40.0-m hill (frictionless). Find speed: **a.** at the valley bottom, **b.** at top of 2nd hill. **c.** Do the hill angles matter?

Given	$h_1 = 45.0$ m, $h_2 = 40.0$ m, $v_1 = 0$
Step 1	**Part (a): Valley bottom ($h = 0$):** $v = \sqrt{2gh_1} = \sqrt{2 \times 9.8 \times 45.0} =$ **29.7 m/s**
Step 2	**Part (b): Top of 40.0-m hill:** $v = \sqrt{2g(h_1 - h_2)} = \sqrt{2 \times 9.8 \times 5.0} =$ **9.90 m/s**
Step 3	**Part (c): Effect of angles: No**—without friction, final speed depends only on vertical height change Δh.
Answer	**a) 29.7 m/s | b) 9.90 m/s | c) No**

PRACTICE PROBLEM 42 **FRQ · FREE RESPONSE** Student Book p. 28

In a splash contest, Diver 1 (136 kg) simply steps off a 3.00-m platform. How high above the platform must Diver 2 (100 kg) leap to hit the water with the same kinetic energy?

Given	m_1 = 136 kg, h_1 = 3.00 m; m_2 = 100 kg
Step 1	**Equate impact kinetic energies:** $m_1gh_1 = m_2gh_2 \rightarrow h_2 = \frac{136 \times 3.00}{100}$ = 4.08 m above water
Step 2	**Height above platform:** Δh = 4.08 − 3.00 = **1.08 m** above the platform
Answer	**1.08 m above the platform**

PRACTICE PROBLEM 43 (CHALLENGE) **FRQ · FREE RESPONSE** Student Book p. 28

A pinball spring exerts an average force of 2.0 N on a 0.080-kg uniform sphere ($I = \frac{2}{5}mr^2$) over 5.0 cm. Find its linear speed after leaving the spring.

Given	F = 2.0 N, d = 0.050 m, m = 0.080 kg, $\omega = \frac{v}{r}$
Step 1	**Work done by spring = Total KE:** $W = Fd = 2.0 \times 0.050 = 0.10$ J; $KE_{total} = \frac{1}{2}mv^2 + \frac{1}{2}(\frac{2}{5}mr^2)(\frac{v}{r})^2 = \frac{7}{10}mv^2$
Step 2	**Solve for v:** $v = \sqrt{\frac{10\,W}{7\,m}} = \sqrt{\frac{10 \times 0.10}{7 \times 0.080}}$ = **1.3 m/s** (1.34 m/s)
Answer	**v = 1.3 m/s**

CHECK YOUR PROGRESS 47, 50 & 51 **FRQ · FREE RESPONSE** Student Book p. 32

47. Trampoline energy bars at (a) highest point and (b) lowest point.
50. A rubber ball drops from 8.0 m and loses 1/5 of its ME per bounce. How many bounces until max height is ≤ 4.0 m?
51. A 36.0-kg child slides down a 2.5-m slide and reaches 3.0 m/s at the bottom. Find energy transformed by friction.

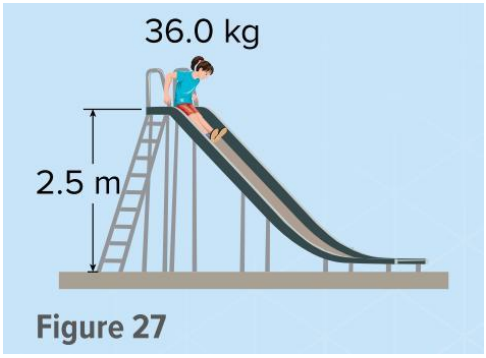


Figure 27

Given	50: $h_n = 8.0(0.80)^n$ | 51: m = 36.0 kg, h = 2.5 m, v_f = 3.0 m/s
Step 1	**CYP 47 (Trampoline):** (a) Highest: 100% **GPE** | (b) Lowest: 100% **Elastic PE**
Step 2	**CYP 50 (Bouncing ball):** n = 1: 6.4 m; n = 2: 5.12 m; n = 3: 4.10 m; n = 4: 3.28 m → **4 bounces**
Step 3	**CYP 51 (Friction on slide):** $E_{friction} = mgh - \frac{1}{2}mv^2 = (36.0)(9.8)(2.5) - \frac{1}{2}(36.0)(3.0)^2 =$ 882 − 162 = **720 J**
Answer	**47) GPE → Elastic PE | 50) 4 bounces | 51) 720 J**

PRACTICE · YOUR TURN **FRQ · FREE RESPONSE** 3 Free-Response questions on FRQ Q17 — rising in difficulty

1 RECALL
Write the equations for translational kinetic energy, rotational kinetic energy, and gravitational potential energy, stating the SI unit of each.

Step 1	**Equations & Units:** $KE_{trans} = \frac{1}{2}mv^2$, $KE_{rot} = \frac{1}{2}I\omega^2$, $GPE = mgh$ — all measured in **joules (J)**.
Answer	**All energies in joules (J)**

2 APPLY

A 1.5-kg ball is dropped from 18.0 m above the ground (no air resistance). Find its speed when it is 5.5 m above the ground.

Given	m = 1.5 kg, h_i = 18.0 m, h_f = 5.5 m
Step 1	**Conservation of ME:** $v = \sqrt{2g(h_i - h_f)} = \sqrt{2 \times 9.8 \times 12.5}$ = **15.7 m/s**
Answer	**v = 15.7 m/s**

3 CHALLENGE

A 42.0-kg child starts from rest at the top of a 3.2-m slide and reaches 4.5 m/s at the bottom. Calculate the mechanical energy lost to friction.

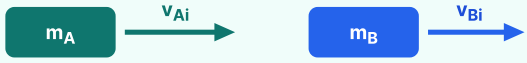
Given	m = 42.0 kg, h = 3.2 m, v_f = 4.5 m/s
Step 1	**Initial & Final ME:** $GPE_i = 42.0 \times 9.8 \times 3.2 = 1317.1$ J; $KE_f = \frac{1}{2}(42.0)(4.5)^2 = 425.3$ J
Step 2	**Thermal loss:** $E_{friction} = 1317.1 - 425.3$ = **892 J**
Answer	**892 J transformed to thermal energy**

Collisions, Momentum & Kinetic Energy

TOPIC PRIMER · CONCEPT GUIDE Analyzing Collisions (Module 10)

Golden Rule: In any closed, isolated collision, **total linear momentum is ALWAYS conserved** ($p_i = p_f$). What distinguishes collision types is what happens to **kinetic energy (KE)**—whether it stays the same, decreases into heat/sound, or increases from stored energy.

BEFORE COLLISION (Total p_i)



AFTER (Closed & Isolated: $p_i = p_f$)

- Elastic:

KEf = KEi (no KE lost) • Inelastic / Stick: **KEf < KEi** (heat/sound) • Superelastic: **KEf > KEi** (stored PE released)

Quantity / Law	Formula	Units & Meaning
Momentum Conservation	$m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$	Always true if $F_{ext} = 0$
Perfectly Inelastic (Stick)	$m_A v_{Ai} + m_B v_{Bi} = (m_A + m_B) v_f$	Objects move together at common v_f
Elastic Collision	$KE_f = KE_i$	Hard objects (billiard balls); no KE loss
Inelastic / Superelastic	Inelastic: $KE_f < KE_i$ | Superelastic: $KE_f > KE_i$	Loss = $KE_i - KE_f$

Watch Out (Common Trap): Never assume $KE_i = KE_f$ during a collision! Use **momentum conservation** to find velocities first, then compare KE_i and KE_f.

Q3	MCQ OBJECTIVE **Compare elastic and inelastic collisions, explain KE loss, and use conservation laws to analyze collisions.**	pp. 29–32 · S.T.B E.P(6) · P.P(44) 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q3 (Elastic vs. Inelastic Collisions) — rising in difficulty

1 **In an inelastic collision inside a closed, isolated system:**

A both momentum and kinetic energy are conserved	**B momentum is conserved, but kinetic energy decreases**
C kinetic energy is conserved, but momentum decreases	D neither momentum nor kinetic energy is conserved

Answer: B — Momentum is always conserved in an isolated system, while some KE turns into thermal/sound energy.

2 **A 1000-kg car at 12 m/s collides and locks onto a stationary 2000-kg truck. Their common speed just after impact is:**

A 3.0 m/s	**B 4.0 m/s**
C 6.0 m/s	D 12 m/s

Answer: B — $v_f = \frac{1000 \times 12}{1000 + 2000} = \frac{12\,000}{3000} = \mathbf{4.0\ m/s}$.

3 **Before a collision, two carts have total KE_i = 8.0 J. After colliding, their total KE_f = 11.5 J. This collision is:**

A elastic	B perfectly inelastic
C superelastic (explosive)	D impossible

Answer: C — Since $KE_f > KE_i$, stored potential energy was released → **superelastic collision**.

PRACTICE PROBLEM 44 Student Book p. 32

An 8.00-g bullet is fired horizontally into a 9.00-kg block of wood on a frictionless air table and becomes embedded in it. Together they slide at 10.0 cm/s. Find the initial speed of the bullet.

Given	$m_b = 0.00800$ kg, $m_w = 9.00$ kg, $v_f = 0.100$ m/s
Step 1	**Apply momentum conservation:** $m_b v_{bi} + \cancel{m_w(0)} = (m_b + m_w)v_f$
Step 2	**Solve for v_{bi}:** $v_{bi} = \frac{(0.00800 + 9.00)(0.100)}{0.00800} = \frac{0.9008}{0.00800} =$ **113 m/s** (112.6 m/s)
Answer	**v_{bi} = 113 m/s**

FRQ Q18

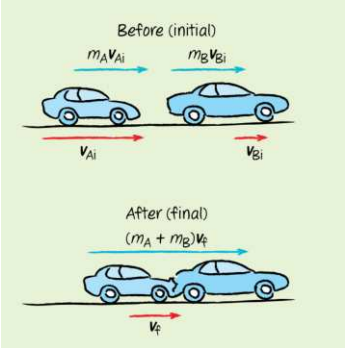
FRQ · FREE RESPONSE

Analyze 1D collisions to calculate momenta, velocities, and kinetic energy changes before and after impact.

pp. 31–32 · E.P(6) P.P(45,46) · C.Y.P(49) 8–11 marks

EXAMPLE PROBLEM 6 **FRQ · FREE RESPONSE** Student Book p. 31

A 1150-kg compact car moving at 15.0 m/s smashes into the rear of a 1575-kg car moving at 5.0 m/s in the same direction, and they lock together. Find: **a.** final velocity, and **b.** decrease in kinetic energy.



Given $m_A = 1150$ kg, $v_{Ai} = 15.0$ m/s; $m_B = 1575$ kg, $v_{Bi} = 5.0$ m/s

Initial Momentum (p_i) ①

$p_i = m_A v_{Ai} + m_B v_{Bi}$

$p_i = 1150(15.0) + 1575(5.0)$

Final Momentum (p_f) ②

$p_f = (m_A + m_B)v_f$

$p_f = 2725\ v_f$

Step 1 **Part (a): Solve Eq. 1 = Eq. 2 for v_f:** $v_f = \dfrac{1150(15.0) + 1575(5.0)}{1150 + 1575} = \dfrac{25\,125}{2725} =$ **9.2 m/s**

Step 2 **Part (b): Initial & Final KE:** $KE_i = \frac{1}{2}(1150)(15.0)^2 + \frac{1}{2}(1575)(5.0)^2 = 149\,063$ J

$KE_f = \frac{1}{2}(2725)(9.220)^2 = 115\,829$ J → $\Delta KE =$ **3.3×10^4 J** decrease

Answer **a) 9.2 m/s | b) 3.3×10^4 J decrease**

PRACTICE PROBLEM 45 **FRQ · FREE RESPONSE** Student Book p. 32

A 91.0-kg hockey player skating at 5.50 m/s is hit from behind by an equal-mass player moving at 8.1 m/s in the same direction; they slide together. Find: **a.** initial KE and momentum, **b.** final velocity, **c.** KE lost.

Given	$m_1 = m_2 = 91.0$ kg, $v_{1i} = 5.50$ m/s, $v_{2i} = 8.1$ m/s
Step 1	**Part (a): Initial KE & Momentum:** $KE_i = \frac{1}{2}(91.0)(5.50^2 + 8.1^2) =$ **4.36×10^3 J**; $p_i = 91.0(5.50 + 8.1) =$ **1.24×10^3 kg·m/s**
Step 2	**Part (b): Final velocity:** $v_f = \frac{1237.6}{182.0} =$ **6.8 m/s**
Step 3	**Part (c): KE decreased:** $KE_f = \frac{1}{2}(182.0)(6.8)^2 = 4207.8$ J → Loss = 4361.6 − 4207.8 = **1.5×10^2 J** (154 J)
Answer	**a) 4.36×10^3 J, 1.24×10^3 kg·m/s | b) 6.8 m/s | c) 1.5×10^2 J**

PRACTICE PROBLEM 46 (CHALLENGE) **FRQ · FREE RESPONSE** Student Book p. 32

A 0.73-kg magnetic target hangs on a string. A 0.025-kg dart strikes it head-on, and they swing 12.0 cm above the initial level before stopping. **a.** Choose a system. **b.** State what is conserved in each stage. **c.** Find the dart's initial velocity.

VISUAL DIAGRAM / SETUP



Given	$m_d = 0.025$ kg, $m_t = 0.73$ kg, $M = 0.755$ kg, $h = 0.120$ m
Step 1	**Part (a) & (b): Two stages:** System: dart + target + Earth. Stage 1 (Collision): **Momentum** conserved (inelastic). Stage 2 (Swing): **Mechanical Energy** conserved (KE → GPE).
Step 2	**Part (c): Work backward from Stage 2 → Stage 1:** Stage 2: $v_{after} = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 0.120} = 1.534$ m/s Stage 1: $v_{dart} = \frac{M\, v_{after}}{m_d} = \frac{0.755 \times 1.534}{0.025} =$ **46 m/s** (46.3 m/s)
Answer	**a) Dart+target+Earth | b) Momentum then ME | c) 46 m/s**

CHECK YOUR PROGRESS 49 **FRQ · FREE RESPONSE** Student Book p. 32

A glob of chewing gum and a small rubber ball collide head-on in midair and rebound apart. Is kinetic energy conserved? If not, what happens to it?

Given	Deformation of soft chewing gum
Step 1	**Analysis: No:** kinetic energy is **not conserved** because deforming the soft gum transforms KE into **thermal energy and sound**.
Answer	**No; lost to thermal energy and sound**

PRACTICE · YOUR TURN **FRQ · FREE RESPONSE** 3 Free-Response questions on FRQ Q18 — rising in difficulty

1 RECALL

Explain the difference between an elastic collision and a perfectly inelastic collision in terms of momentum and kinetic energy.

Step 1	**Comparison:** In both, **momentum is conserved**. In an elastic collision, **KE is conserved**; in a perfectly inelastic collision, objects stick together and **KE decreases**.
Answer	**Momentum conserved in both; KE conserved only in elastic**

2 APPLY

A 1400-kg car at 18.0 m/s rear-ends a 1000-kg car at 6.0 m/s and they lock together. Find their common final speed and the KE lost.

Given	$m_1 = 1400$ kg, $v_{1i} = 18.0$ m/s; $m_2 = 1000$ kg, $v_{2i} = 6.0$ m/s
Step 1	**Final speed:** $v_f = \frac{1400(18.0) + 1000(6.0)}{2400} = \frac{31\,200}{2400} =$ **13.0 m/s**
Step 2	**KE lost:** $KE_i = 244\,800$ J; $KE_f = 202\,800$ J → Loss = **4.2×10^4 J**
Answer	**$v_f = 13.0$ m/s; KE lost = 4.2×10^4 J**

3 CHALLENGE

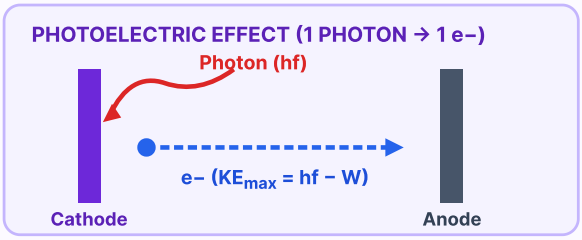
A 0.020-kg bullet embeds in a 1.98-kg suspended block, causing them to swing upward 0.20 m. Find the bullet's initial speed.

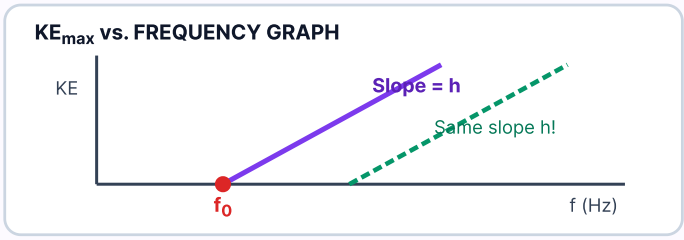
Given	$m_b = 0.020$ kg, $M = 2.00$ kg, $h = 0.20$ m
Step 1	**Swing speed:** $v_{after} = \sqrt{2 \times 9.8 \times 0.20} = 1.980$ m/s
Step 2	**Initial bullet speed:** $v_b = \frac{2.00 \times 1.980}{0.020} =$ **1.98×10^2 m/s**
Answer	**$v_b = 198$ m/s**

Thermal Radiation, Photons & The Photoelectric Effect

TOPIC PRIMER · CONCEPT GUIDE Quantum Packets & Photoelectric Effect (Module 22)

Why Classical Physics Failed: Wave theory predicted that *brighter* light (higher intensity) should always eject electrons, even at low frequencies. Instead, experiments showed electrons eject **only** if frequency exceeds a metal's **threshold frequency (f_0)**. Einstein explained this by treating light as discrete energy packets called **photons** (1 photon gives all its energy to 1 electron).





Quantity / Law	Formula	Units & Meaning
Planck's Quantized Energy	$E = nhf$	$h = 6.626 \times 10^{-34}$ J·s; $n = 0, 1, 2, \ldots$
Photon Energy (J and eV)	$E = hf = \frac{hc}{\lambda} = \frac{1240\ \text{eV·nm}}{\lambda}$	1 eV = 1.602×10^{-19} J
Photoelectric Equation	$KE_{max} = hf - W = hf - hf_0$	$W = hf_0$ = work function
Stopping Potential	$KE_{max} = -e\Delta V_0 = e\,V_0$	In eV, KE_{max} equals V_0 numerically

Watch Out (Common Trap): Increasing light **intensity** (above f_0) increases the **number of photons** (current), NOT the energy per photon (KE_{max})!

Q4 & Q5

MCQ OBJECTIVE

Describe thermal emission spectra vs. temperature, Planck's energy quantization ($E = nhf$), and calculate photon energy.

pp. 46–48, 52
P.P(2, 3, 4)
2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q4 & Q5 (Thermal Spectra & Photons) — rising in difficulty

1 As the temperature of a glowing hot object increases, the peak frequency of its emission spectrum:

A decreases
B increases
C stays constant
D drops to zero

Answer: B — Hotter objects emit higher-frequency peaks (red → yellow → white) and more total energy.

2 According to Planck, a vibrating atom can only emit or absorb energy in discrete amounts given by:

A $E = mc^2$	**B** ***E = nhf***
C $E = \frac{1}{2}hf$	D $E = h/\lambda^2$

Answer: B — Energy is quantized in integer multiples: ***E = nhf***.

3 A photon has a wavelength of 496 nm. Its energy in electron volts is:

A 1.50 eV	**B 2.50 eV**
C 3.10 eV	D 4.00 eV

Answer: B — $E = \frac{1240\ \text{eV·nm}}{496\ \text{nm}} =$ **2.50 eV**.

PRACTICE PROBLEM 2 Student Book p. 52

A photon's energy is 2.03 eV. What is the photon's wavelength?

Given	$E = 2.03$ eV, $hc = 1240$ eV·nm
Step 1	**Rearrange $E = 1240 / \lambda$:** $\lambda = \frac{1240\ \text{eV·nm}}{2.03\ \text{eV}} =$ **611 nm**
Answer	**λ = 611 nm**

PRACTICE PROBLEM 3 Student Book p. 52

Rank the following photons from least to greatest energy: **a.** 4.0 eV, **b.** 320 nm, **c.** 811 nm, **d.** 2.1 eV.

Given	Convert wavelengths to eV using $E = 1240 / \lambda$
Step 1	**Convert (b) and (c) to eV:** b) $\frac{1240}{320} =$ **3.88 eV**; c) $\frac{1240}{811} =$ **1.53 eV**
Step 2	**Order from least to greatest:** **c (1.53 eV) < d (2.1 eV) < b (3.88 eV) < a (4.0 eV)**
Answer	**c < d < b < a**

PRACTICE PROBLEM 4 (CHALLENGE) Student Book p. 52

The visible light spectrum spans wavelengths from 400 nm to 700 nm. What is the range of photon energies in visible light?

Given	λ_{min} = 400 nm (violet), λ_{max} = 700 nm (red)
Step 1	**Minimum & Maximum energies:** $E_{min} = \frac{1240}{700} =$ **1.77 eV**; $E_{max} = \frac{1240}{400} =$ **3.10 eV**
Answer	**1.77 eV to 3.10 eV**

Q6, Q7 & Q8	**MCQ OBJECTIVE** **Define photoelectric effect, threshold frequency, eV, and work function; calculate KE_{max} & stopping potential; interpret KE_{max}–f graphs.**	pp. 49–58 E.P(1,2) · P.P(5–11) C.Y.P(16,17,21) · 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q6 – Q8 (Photoelectric Effect & Graphs) — rising in difficulty

1 **Which quantity determines whether electrons are ejected from a metal surface?**

A light intensity
B exposure time
C photon frequency
D surface area

Answer: C — Electrons eject only when incident **frequency** $f \geq f_0$.

2 **On a graph of maximum photoelectron kinetic energy versus incident frequency, the slope of the line equals:**

A the work function
B Planck's constant *h*
C the threshold frequency
D the stopping potential

Answer: B — From $KE_{max} = hf - W$, the slope is **Planck's constant *h*** and the x-intercept is f_0.

3 **Light of photon energy 4.10 eV strikes a metal with work function 2.35 eV. The stopping potential is:**

A 1.75 V
B 2.35 V
C 4.10 V
D 6.45 V

Answer: A — KE_{max} = 4.10 − 2.35 = 1.75 eV → V_0 = **1.75 V**.

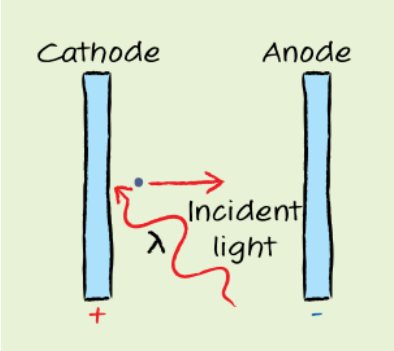
CHECK YOUR PROGRESS 16, 17 & 21 Student Book p. 58

16. Why can't high-intensity, low-frequency light eject electrons, whereas low-intensity, high-frequency light can?
17. As temperature rises, how do peak frequency and total radiated energy change?
21. Find the energy (in eV) of photons from a 650-nm laser pointer.

Given	$E = 1240\ \text{eV·nm} / \lambda$
Step 1	**CYP 16 & 17:** 16: Each low-frequency photon has $hf < W$; electrons absorb 1 photon at a time. 17: Both **peak frequency** and **total radiated energy** increase.
Step 2	**CYP 21:** $E = \dfrac{1240\ \text{eV·nm}}{650\ \text{nm}} =$ **1.91 eV**
Answer	**16) $hf < W$ | 17) Both increase | 21) 1.91 eV**

EXAMPLE PROBLEM 1 Student Book p. 54

The stopping potential difference of a photocell is 4.0 V. How much kinetic energy does the incident light give the electrons, in joules and in electron volts?



Given	$\Delta V_0 = 4.0\ \text{V}, \quad e = -1.60 \times 10^{-19}\ \text{C}$
Step 1	**Kinetic energy in J:** $KE = -e\Delta V_0 = -(-1.60 \times 10^{-19}\ \text{C})(4.0\ \text{V}) =$ **6.4×10^{-19} J**
Step 2	**Kinetic energy in eV:** $KE = \dfrac{6.4 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{J/eV}} =$ **4.0 eV**
Answer	**6.4×10^{-19} J | 4.0 eV**

PRACTICE PROBLEMS 5, 6 & 7 Student Book p. 54

5. An electron has 2.3 eV; find its KE in joules. **6.** Find its velocity. **7.** Find the KE in eV of an electron moving at 6.2×10^6 m/s.

Given	$m_e = 9.11 \times 10^{-31}$ kg, $1\text{ eV} = 1.60 \times 10^{-19}$ J
Step 1	**Problem 5:** $KE = 2.3 \times 1.60 \times 10^{-19} =$ **3.7×10^{-19} J**
Step 2	**Problem 6:** $v = \sqrt{\frac{2\,KE}{m_e}} = \sqrt{\frac{2(3.68 \times 10^{-19})}{9.11 \times 10^{-31}}} =$ **9.0×10^5 m/s**
Step 3	**Problem 7:** $KE = \frac{0.5(9.11 \times 10^{-31})(6.2 \times 10^6)^2}{1.60 \times 10^{-19}} =$ **1.1×10^2 eV** (109 eV)
Answer	**5) 3.7×10^{-19} J | 6) 9.0×10^5 m/s | 7) 1.1×10^2 eV**

PRACTICE PROBLEMS 8, 9, 10 & 11 Student Book p. 54

8. Stopping potential = 5.7 V; find KE_{max} in eV. **9.** Stopping potential = 5.1 V; find KE in J. **10.** $KE_{max} = 7.5 \times 10^{-19}$ J; find stopping potential. **11.** Stopping potential = 3.2 V; find KE_{max} in J.

Given	$KE_{max} = eV_0$
Step 1	**Problems 8 & 9:** 8: **5.7 eV** | 9: $5.1 \times 1.60 \times 10^{-19} =$ **8.2×10^{-19} J**
Step 2	**Problems 10 & 11:** 10: $V_0 = \frac{7.5 \times 10^{-19}}{1.60 \times 10^{-19}} =$ **4.7 V** | 11: $3.2 \times 1.60 \times 10^{-19} =$ **5.1×10^{-19} J**
Answer	**8) 5.7 eV | 9) 8.2×10^{-19} J | 10) 4.7 V | 11) 5.1×10^{-19} J**

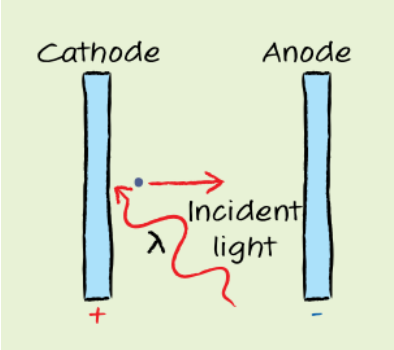
FRQ Q19 | FRQ · FREE RESPONSE

Solve multi-step photoelectric problems (photon energy, work function, KE_{max}) and interpret KE_{max}–f graphs.

pp. 55–58 · E.P(2) P.P(12–15) · C.Y.P(20) 8–11 marks

EXAMPLE PROBLEM 2 | FRQ · FREE RESPONSE | Student Book p. 56

A photocell uses a sodium cathode with threshold wavelength λ_0 = 526 nm. **a.** Find the work function of sodium in eV. **b.** If 348-nm UV light strikes it, will electrons be ejected? If so, find their maximum KE in eV.



Given	λ_0 = 526 nm, λ = 348 nm
Step 1	**Part (a): Work function:** $W = \frac{1240\ \text{eV·nm}}{526\ \text{nm}}$ = **2.36 eV**
Step 2	**Part (b): Incident photon energy & KE:** $E = \frac{1240}{348}$ = 3.56 eV > 2.36 eV → **Yes, ejected!** $KE_{max} = E - W = 3.56 - 2.36$ = **1.20 eV**
Answer	**a) 2.36 eV | b) Yes, 1.20 eV**

PRACTICE PROBLEMS 12, 13 & 14 | FRQ · FREE RESPONSE | Student Book p. 56

12. Zinc has λ_0 = 310 nm; find f_0 (Hz) and work function (eV).
13. Cesium (W = 1.95 eV) is hit by 425-nm light; find KE_{max} (eV).
14. 193-nm UV light ejects 3.5-eV electrons; find the metal's work function.

Given	$c = 3.00 \times 10^8$ m/s, $KE_{max} = E - W$
Step 1	**Problem 12 (Zinc):** $f_0 = \frac{3.00 \times 10^8}{310 \times 10^{-9}}$ = **9.68×10^{14} Hz**; $W = \frac{1240}{310}$ = **4.00 eV**
Step 2	**Problem 13 (Cesium):** $E = \frac{1240}{425}$ = 2.92 eV → KE_{max} = 2.92 − 1.95 = **0.97 eV**
Step 3	**Problem 14 (Work function):** $E = \frac{1240}{193}$ = 6.42 eV → W = 6.42 − 3.5 = **2.9 eV**
Answer	**12) 9.68×10^{14} Hz, 4.00 eV | 13) 0.97 eV | 14) 2.9 eV**

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PRACTICE PROBLEM 15 & C.Y.P 20 **FRQ · FREE RESPONSE** Student Book pp. 56, 58

P.P 15: Longest wavelength to eject electrons from a metal is 273 nm. Find work function and identify the metal from Figure 9 / Table 1.
CYP 20: Green light (532 nm) strikes a metal; stopping potential is 1.44 V. Find the work function in eV.

Table 1 Threshold Frequency, Threshold Wavelength, and Work Function for Selected Metals

Metal	Threshold Frequency ($\times 10^{14}$ Hz)	Threshold Wavelength (nm)	Work Function (eV)
Cesium	4.70	637	1.95
Magnesium	8.84	339	3.66
Silver	11.1	270	4.6
Sodium	5.70	526	2.36

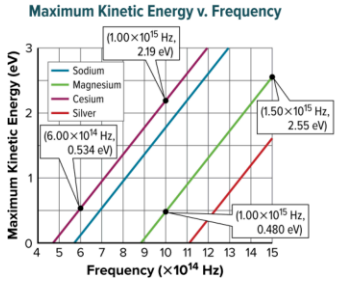


Figure 9 The metal's threshold frequency equals the line's x-intercept. Each line's slope equals Planck's constant.

Given	$W = 1240 / \lambda_0$
Step 1	**P.P 15:** $W = \frac{1240}{273}$ = **4.54 eV** → Closest to **Silver** (4.6 eV, 270 nm).
Step 2	**CYP 20:** $E = \frac{1240}{532}$ = 2.33 eV → W = 2.33 − 1.44 = **0.89 eV**
Answer	**15) 4.54 eV (Silver) | CYP 20) 0.89 eV**

PRACTICE · YOUR TURN **FRQ · FREE RESPONSE** 3 Free-Response questions on FRQ Q19 — rising in difficulty

1 RECALL

Define threshold frequency and work function, and write Einstein's photoelectric equation.

Step 1	**Definitions & Equation:** f_0 is the minimum frequency to eject electrons; $W = hf_0$ is the minimum energy to free an electron. $\boldsymbol{KE_{max} = hf - W}$.
Answer	$\boldsymbol{KE_{max} = hf - hf_0}$

2 APPLY

Light of wavelength 310 nm strikes potassium (work function 2.29 eV). Find the photon energy, KE_{max} in eV, and stopping potential.

Given	λ = 310 nm, W = 2.29 eV
Step 1	**Photon energy & KE:** $E = \frac{1240}{310}$ = 4.00 eV → KE_{max} = 4.00 − 2.29 = **1.71 eV** → V_0 = **1.71 V**
Answer	$\boldsymbol{E}$ **= 4.00 eV;** $\boldsymbol{KE_{max}}$ **= 1.71 eV;** $\boldsymbol{V_0}$ **= 1.71 V**

3 CHALLENGE

In a photoelectric experiment, 400-nm light produces a stopping potential of 1.25 V. Find the metal's work function and threshold wavelength.

Given	$\lambda = 400$ nm, $V_0 = 1.25$ V
Step 1	**Work function:** $E = \frac{1240}{400} = 3.10$ eV → $W = 3.10 - 1.25 =$ **1.85 eV**
Step 2	**Threshold wavelength:** $\lambda_0 = \frac{1240}{1.85} =$ **670 nm**
Answer	$W = 1.85$ eV; $\lambda_0 = 670$ nm

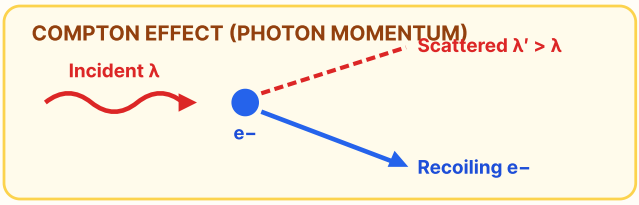
UNIT 4 · Q9, Q10, Q11

Wave-Particle Duality, Compton Effect & Uncertainty

Warm Amber · Module 22 (pp. 57–61)

TOPIC PRIMER · CONCEPT GUIDE Photons Have Momentum; Particles Have Waves (Module 22)

Symmetry of Nature: Not only do light waves act like particles (photons carrying momentum $p = h/\lambda$), but moving particles like electrons also behave like waves with a **de Broglie wavelength** $\lambda = h/(mv)$. Because measuring a tiny particle's position with short-wavelength light kicks its momentum (Compton effect), Heisenberg showed we can never know both x and p with unlimited precision.



DE BROGLIE & UNCERTAINTY

- Matter wave:

$\lambda = h / mv$ (smaller m → larger λ) • Accelerated e−: **$eV = \frac{1}{2}mv^2$** → find v, then λ • Heisenberg: **$\Delta x \uparrow \leftrightarrow \Delta p \downarrow$** (cannot pinpoint both)

Quantity / Law	Formula	Units & Meaning
Photon Momentum	$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$	kg·m/s; proves light has particle momentum
Compton Effect	$\lambda' > \lambda$ (photon loses E & p)	Energy & momentum conserved in photon–e^- collision
de Broglie Wavelength	$\lambda = \frac{h}{p} = \frac{h}{mv}$	Verified by electron diffraction
Accelerated Charge Speed	$e\Delta V = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2e\Delta V}{m}}$	$m_e = 9.11 \times 10^{-31}$ kg, $e = 1.602 \times 10^{-19}$ C

Watch Out (Common Trap): Everyday objects (like bowling balls) have huge mass m, so $\lambda = h/(mv) \approx 10^{-35}$ m—far too tiny to diffract or show wave behavior!

Q9	MCQ OBJECTIVE **Calculate photon momentum ($p = h/\lambda$), explain the Compton effect, and apply conservation of energy & momentum.**	pp. 57–58 · S.T.B C.Y.P(18, 24) 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q9 (Compton Effect & Photon Momentum) — rising in difficulty

1 **In the Compton effect, when X-ray photons scatter off electrons in graphite, the scattered photons have:**

A shorter wavelength and higher energy

B longer wavelength and lower energy

C the same wavelength and higher momentum

D zero momentum

Answer: B — Photons transfer energy and momentum to electrons, so scattered photons have lower E and **longer λ**.

2 **The momentum of a 500-nm photon is closest to:**

A 1.33×10^{-27} kg·m/s

B 3.31×10^{-25} kg·m/s

C 1.33×10^{-36} kg·m/s

D 6.63×10^{-34} kg·m/s

Answer: A — $p = \dfrac{6.63 \times 10^{-34}}{500 \times 10^{-9}} = \mathbf{1.33 \times 10^{-27}\ kg{\cdot}m/s}$.

3 **The Compton effect provides direct experimental evidence that:**

A light is purely a longitudinal wave

B photons carry momentum and obey collision conservation laws

C electrons have zero mass

D X-rays cannot diffract

Answer: B — Photon–electron collisions obey **conservation of energy and momentum**.

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CHECK YOUR PROGRESS 18 & 24 Student Book p. 58

18. Distinguish the photoelectric effect from the Compton effect.
24. If an X-ray photon collides with a massive proton instead of an electron, would the proton gain as much energy? Would the photon lose as much energy?

Photons and conservation of energy and momentum In later experiments, Compton observed that electrons were ejected from the graphite block during the experiment. He suggested that the X-ray photons collided with electrons in the graphite target and transferred energy and momentum to them. Compton thought these photon-electron collisions were similar to the elastic collisions experienced by billiard balls, as shown in **Figure 11**. He tested this idea by measuring the energies of the electrons ejected from the graphite block. Compton found that the energy and momentum gained by the ejected electrons equaled the energy and momentum lost by the photons. Thus, photons obey the laws of conservation of energy and momentum when they collide with other particles.

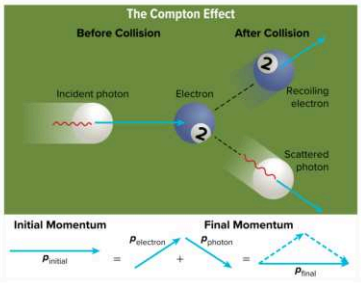


Figure 11 The laws of conservation of energy and momentum apply to collisions between billiard balls and between photons and particles.

Given	Mass of proton ≈ 1836 × mass of electron
Step 1	**CYP 18: Photoelectric:** photon is completely absorbed and ejects an electron from a metal. **Compton:** photon scatters off a free/loosely bound electron with longer wavelength (λ′ > λ).
Step 2	**CYP 24:** **No** to both—like a ping-pong ball hitting a bowling ball, the massive proton recoils very little and the photon loses almost no energy.
Answer	**18) Absorbed vs. scattered | 24) No; proton gains much less, photon loses much less**

Q10 — MCQ OBJECTIVE

Describe de Broglie's matter-wave hypothesis (verified by electron diffraction) and calculate de Broglie wavelength (λ = *h*/*mv*).

pp. 59–61 · E.P(3) P.P(25–28) · C.Y.P(29,31) 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q10 (de Broglie Matter Waves) — rising in difficulty

1 **De Broglie's hypothesis of matter waves was confirmed experimentally by observing:**

A photoelectric emission
B electron diffraction
C alpha scattering
D blackbody radiation

Answer: B — Electron diffraction (an interference pattern) proved particles have wave properties.

2 **An electron (m = 9.11 × 10^{-31} kg) moves at 4.0 × 10^{6} m/s. Its de Broglie wavelength is:**

A 1.8 × 10^{-10} m
B 5.5 × 10^{9} m
C 2.4 × 10^{-12} m
D 7.3 × 10^{-10} m

Answer: A — $\lambda = \dfrac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(4.0 \times 10^{6})} = \mathbf{1.8 \times 10^{-10}\ m}$.

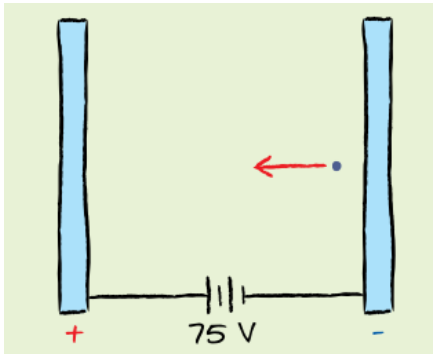
3 **If an electron and a proton have the same speed, which has the longer de Broglie wavelength?**

A The proton, because it has greater mass	**B** **The electron, because it has smaller mass**
C Both have the same wavelength	**D** Neither has a wavelength

Answer: B — Since $\lambda = \frac{h}{mv}$, smaller mass gives a **longer wavelength**.

EXAMPLE PROBLEM 3 Student Book p. 60

An electron is accelerated from rest by a potential difference of 75 V. What is its de Broglie wavelength?



Given	$\Delta V = 75$ V, $m_e = 9.11 \times 10^{-31}$ kg, $e = 1.602 \times 10^{-19}$ C
Step 1	**Find electron speed v from $e\Delta V = \frac{1}{2}mv^2$:** $v = \sqrt{\frac{2e\Delta V}{m_e}} = \sqrt{\frac{2(1.602 \times 10^{-19})(75)}{9.11 \times 10^{-31}}} = 5.14 \times 10^6$ m/s
Step 2	**Find de Broglie wavelength λ:** $\lambda = \frac{h}{m_e v} = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(5.14 \times 10^6)} =$ **1.4×10^{-10} m** (0.14 nm)
Answer	**$\lambda = 1.4 \times 10^{-10}$ m (0.14 nm)**

PRACTICE PROBLEMS 25 & 26 Student Book p. 60

25. Find the speed and de Broglie wavelength of an electron accelerated by 250 V.
26. A 7.0-kg bowling ball rolls at 8.5 m/s. Find its de Broglie wavelength and explain why it shows no observable wave behavior.

Given	$h = 6.63 \times 10^{-34}$ J·s
Step 1	**Problem 25 (250-V electron):** $v = \sqrt{\frac{2(1.602 \times 10^{-19})(250)}{9.11 \times 10^{-31}}} =$ **9.4×10^{6} m/s**; $\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(9.38 \times 10^{6})} =$ **7.8×10^{-11} m**
Step 2	**Problem 26 (Bowling ball):** $\lambda = \frac{6.63 \times 10^{-34}}{(7.0)(8.5)} =$ **1.1×10^{-35} m** (far too small to diffract through any opening).
Answer	**25) 9.4×10^{6} m/s, 7.8×10^{-11} m | 26) 1.1×10^{-35} m (too small to observe)**

PRACTICE PROBLEMS 27 & 28 Student Book p. 60

27. What potential difference is needed to accelerate an electron so it has a 0.125-nm wavelength?
28. CHALLENGE: Find the kinetic energy (in eV) of a proton with the same 0.14-nm wavelength as the electron in E.P 3.

Given	27: $\lambda = 1.25 \times 10^{-10}$ m | 28: $m_p = 1.67 \times 10^{-27}$ kg, $\lambda = 1.4 \times 10^{-10}$ m
Step 1	**Problem 27:** $v = \frac{h}{m_e \lambda} = 5.82 \times 10^{6}$ m/s → $\Delta V = \frac{m_e v^2}{2e} =$ **96 V** (96.4 V)
Step 2	**Problem 28 (Proton KE):** $p = \frac{h}{\lambda} = 4.74 \times 10^{-24}$ kg·m/s → $KE = \frac{p^2}{2m_p e} =$ **0.042 eV**
Answer	**27) 96 V | 28) 0.042 eV**

CHECK YOUR PROGRESS 29 & 31 Student Book p. 61

29. Why is the wave nature of everyday objects not obvious?
31. Find the de Broglie wavelength of an electron accelerated through 125 V.

Given	$\lambda = h / mv$
Step 1	**CYP 29:** Everyday objects have huge masses, making $\lambda \approx 10^{-35}$ m—far smaller than any atom or slit.
Step 2	**CYP 31:** $v = \sqrt{\frac{2(1.602 \times 10^{-19})(125)}{9.11 \times 10^{-31}}} = 6.63 \times 10^{6}$ m/s $\rightarrow$ $\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(6.63 \times 10^{6})}$ = **1.10×10^{-10} m**
Answer	**29) Mass too large (λ too tiny) | 31) 1.10×10^{-10} m (0.110 nm)**

Q11 MCQ OBJECTIVE

State Heisenberg's uncertainty principle and explain the fundamental limit on simultaneously measuring position and momentum.

p. 61 · S.T.B C.Y.P(32) 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q11 (Heisenberg Uncertainty Principle) — rising in difficulty

1 The Heisenberg uncertainty principle states that it is impossible to simultaneously measure a particle's exact:

A mass and charge
B position and momentum
C charge and spin
D mass and temperature

Answer: B — There is a fundamental limit on knowing both **position and momentum** simultaneously.

2 Using shorter-wavelength photons to locate an electron more precisely causes:

A greater uncertainty in position and smaller uncertainty in momentum
B smaller uncertainty in position and greater uncertainty in momentum
C both uncertainties to become zero
D the electron to stop moving

Answer: B — Shorter λ reduces diffraction ($\Delta x \downarrow$), but higher photon momentum kicks the electron harder ($\Delta p \uparrow$).

3 Why are Heisenberg uncertainty effects unnoticeable for a rolling soccer ball?

A The ball has no momentum
B Planck's constant *h* is extremely small compared to macroscopic masses
C The ball moves slower than light
D Gravity cancels uncertainty

Answer: B — Because *h* is tiny, quantum limits are only noticeable on the atomic scale.

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CHECK YOUR PROGRESS 32 Student Book p. 61

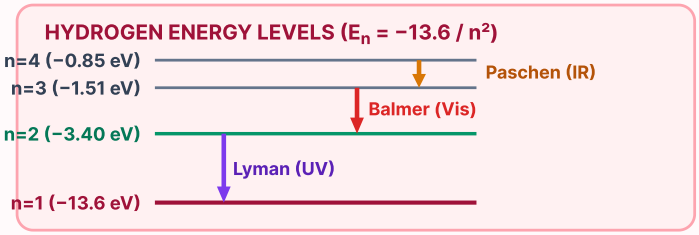
How does the Heisenberg uncertainty principle explain double-slit interference patterns even when electrons or photons pass through one at a time?

Given	Wave–particle duality at the slits
Step 1	**Explanation:** To pass through a narrow slit, each particle's position is localized (Δx small), which creates a **large uncertainty in its transverse momentum (Δp)**, spreading its probability wave across the screen to build the interference pattern.
Answer	**Localizing position at the slit increases momentum uncertainty, spreading the wave.**

Atomic Models, Spectra, Bohr Atom & Lasers

TOPIC PRIMER · CONCEPT GUIDE From Rutherford's Nucleus to Bohr Orbits & Lasers (Module 22)

Evolution of the Atom: Rutherford's gold-foil experiment proved the atom has a tiny, dense, positively charged **nucleus**, but classical physics couldn't explain why orbiting electrons didn't spiral inward. Bohr solved this by quantizing orbits: electrons only exist in **stationary states** (E_n) and emit/absorb a photon only when jumping between levels. Later, Schrödinger's quantum model replaced fixed orbits with probability **electron clouds**.



LASERS & STIMULATED EMISSION

- Pump with

shorter λ (higher energy) • Emits 2 identical, **in-phase** photons 4 Key Laser Properties: 1. Coherent 2. Monochromatic 3. Directional (narrow) 4. Intense

Quantity / Law	Formula	Units & Meaning
Hydrogen Energy Levels	$E_n = -13.6\ \text{eV} \times \frac{1}{n^2}$	Negative = bound state; 0 eV = ionized
Orbital Radius (Hydrogen)	$r_n = r_1 n^2$ ($r_1 = 0.053$ nm)	Radius grows as n^2
Photon Emission / Absorption	$E_{photon} = \lvert E_i - E_f \rvert = hf = \frac{1240\ \text{eV·nm}}{\lambda}$	Emission: high → low; Absorption: low → high
Hydrogen Spectral Series	Lyman (→ n=1, UV); Balmer (→ n=2, Vis); Paschen (→ n=3, IR)	Unique fingerprint per element

Watch Out (Common Trap): Remember: higher n means **less negative** (higher) energy! So jumping from n = 4 to n = 2 emits a photon of energy −0.85 − (−3.40) = **+2.55 eV**.

Q12 & Q13	MCQ OBJECTIVE **Compare Thomson, Rutherford, and Bohr models; distinguish continuous, emission, and absorption spectra as atomic fingerprints.**	pp. 62–66, 74 C.Y.P(40–44) · Get it 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q12 & Q13 (Nuclear Model & Spectra) — rising in difficulty

1 **In Rutherford's gold-foil experiment, a tiny fraction of alpha particles bounced backward because:**

- A electrons are evenly spread like raisins in a muffin
- **B all positive charge and >99.9% of mass sit in a tiny nucleus**
- C gold atoms are solid spheres
- D alpha particles are negatively charged

Answer: B — Large-angle deflections proved the existence of a tiny, dense, positively charged **nucleus**.

2 **Compared with an incandescent bulb filament, a low-pressure glowing gas produces:**

- A a continuous rainbow spectrum
- **B discrete bright emission lines at specific wavelengths**
- C only infrared radiation
- D no light at all

Answer: B — Atomic gases emit **discrete bright-line spectra** that act as unique element fingerprints.

3 **Dark lines in an absorption spectrum appear at:**

- A random wavelengths
- **B the exact same wavelengths as the gas's bright emission lines**
- C half the emission wavelengths
- D only the ultraviolet region

Answer: B — Cool gases absorb the **exact same wavelengths** they emit when excited.

C.Y.P 41, 40, 42, 43 & 44 Student Book p. 74

41. Summarize Rutherford's nuclear model. **40.** How is energy conserved when an atom absorbs a photon?
42. Explain hydrogen's absorption spectrum (Figure 24). **43.** Compare incandescent solids vs. atomic gases.
44. A helium ion's n = 1 radius is 0.0265 nm; find the n = 2 radius.

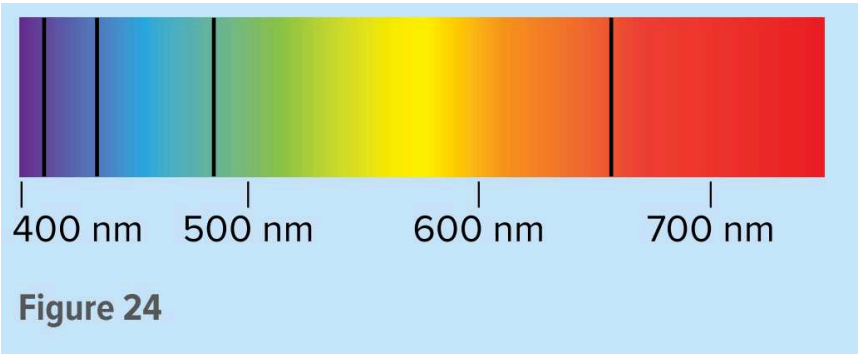


Figure 24

Given	Bohr orbital radius scales as $r_n = r_1\, n^2$
Step 1	**CYP 41 & 40:** 41: Tiny, dense, positive nucleus (>99.9% of mass) surrounded by electrons in mostly empty space. 40: Atom's energy increases by exact photon energy ($\Delta E_{atom} = E_{photon}$).
Step 2	**CYP 42 & 43:** 42: White light passes through cool H_2; dark lines appear where specific wavelengths are absorbed. 43: Solids give **continuous** spectra; gases give **discrete lines** (both are electromagnetic radiation).
Step 3	**CYP 44 (He^+ radius at n = 2):** $r_2 = r_1(2)^2 = 0.0265 \times 4 =$ **0.106 nm**
Answer	**44) r_2 = 0.106 nm**

Q14 & Q15

MCQ OBJECTIVE

Describe Bohr's stationary states, ground/excited states, negative bound-state energy, and r_n / E_n dependence on n.

pp. 67–74 · P.P(33,35) C.Y.P(45,46) · Get it 2–4 marks

CHOOSE THE CORRECT ANSWER 3 MCQs on Q14 & Q15 (Bohr Atom & Quantum Number n) — rising in difficulty

1 **In the Bohr model, an electron in a stationary state:**

A continuously radiates energy and spirals into the nucleus

B does not radiate energy while remaining in that orbit

C can have any continuous energy value

D has positive total energy

Answer: B — Bohr postulated that electrons in stationary states **do not radiate**.

2 **Why are the bound-state energies of the hydrogen atom negative (e.g., −13.6 eV)?**

A Electrons have negative mass	**B Zero energy is defined when the electron is infinitely far away (ionized)**
C Kinetic energy is negative	D Protons repel electrons

Answer: B — Since work must be added to remove an electron to $E = 0$, bound states have **negative energy**.

3 **As the principal quantum number n increases from 1 to 3, the orbital radius of hydrogen:**

A increases by 3×	**B increases by 9×**
C decreases by 9×	D stays unchanged

Answer: B — Since $r_n \propto n^2$, tripling n increases radius by $3^2 = 9$ **times**.

PRACTICE PROBLEMS 33 & 35 Student Book p. 72

33. Calculate the energies of the $n = 2$, 3, and 4 levels in hydrogen.
35. Calculate the energy difference between E_4 and E_2 in hydrogen.

Given	$E_n = -13.6 \text{ eV} / n^2$
Step 1	**Problem 33:** $E_2 = \frac{-13.6}{4} =$ **−3.40 eV**; $E_3 = \frac{-13.6}{9} =$ **−1.51 eV**; $E_4 = \frac{-13.6}{16} =$ **−0.85 eV**
Step 2	**Problem 35:** $\Delta E = E_4 - E_2 = -0.85 - (-3.40) =$ **2.55 eV**
Answer	**33) −3.40, −1.51, −0.85 eV | 35) 2.55 eV**

CHECK YOUR PROGRESS 45 & 46 Student Book p. 74

45. Hydrogen transitions from $n = 101$ to $n = 100$. Find the emitted wavelength and spectral region.
46. If a hydrogen nucleus ($r = 1.5 \times 10^{-15}$ m) were scaled up to a softball ($r = 5$ cm), where would the $n = 1$ electron (5.3×10^{-11} m) be? Inside your classroom?

Given	45: $E_n = -13.6 / n^2$ | 46: Scale = 0.05 m / (1.5×10^{-15} m)
Step 1	**CYP 45 (101 → 100):** $\Delta E = 13.6\left(\frac{1}{100^2} - \frac{1}{101^2}\right) = 2.68 \times 10^{-5}$ eV → $\lambda = \frac{1240 \text{ eV·nm}}{2.68 \times 10^{-5} \text{ eV}}$ = **0.046 m** (4.6 cm, **microwave / radio**)
Step 2	**CYP 46 (Scale model):** $r_{\text{model}} = (5.3 \times 10^{-11}) \times \frac{0.05}{1.5 \times 10^{-15}} =$ **1.8 km** away → **Not** inside the classroom!
Answer	**45) 0.046 m (microwave/radio) | 46) ~1.8 km away (outside classroom)**

Q16 | MCQ OBJECTIVE

Distinguish Lyman, Balmer, and Paschen series; describe quantum electron clouds; explain stimulated emission and lasers.

pp. 75–79 · S.T.B C.Y.P(47–50) · Get it 2–4 marks

CHOOSE THE CORRECT ANSWER

3 MCQs on Q16 (Series, Electron Clouds & Lasers) — rising in difficulty

1 **Which hydrogen spectral series produces visible light?**

A Lyman series (transitions to $n = 1$)

B Balmer series (transitions to $n = 2$)

C Paschen series (transitions to $n = 3$)

D All three series

Answer: B — Transitions ending at ***n* = 2 (Balmer series)** emit visible photons.

2 **In the modern quantum model, the region where an electron has a high probability of being found is called the:**

A planetary ring

B electron cloud

C standing loop

D photon shell

Answer: B — Schrödinger's wave function maps the probability density as an **electron cloud**.

3 **During stimulated emission in a laser, an incoming photon strikes an excited atom and causes:**

A the atom to absorb the photon and ionize

B two identical photons to leave in phase (coherent)

C two photons of different wavelengths to scatter

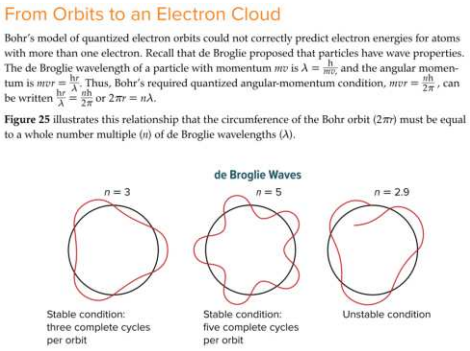
D random thermal emission

Answer: B — Stimulated emission produces **two identical, coherent, in-phase photons**.

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C.Y.P 47, 48, 49 & 50 Student Book p. 79

47. What were the Bohr model's limitations? **48.** Can green light pump a red laser? Can red light pump a green laser?
49. List 4 useful properties of laser light. **50.** Why would shrinking an electron cloud to nuclear size require huge energy?



From Orbits to an Electron Cloud

Bohr's model of quantized electron orbits could not correctly predict electron energies for atoms with more than one electron. Recall that de Broglie proposed that particles have wave properties. The de Broglie wavelength of a particle with momentum mv is $\lambda = \frac{h}{mv}$ and the angular momentum is $mvr = \frac{hr}{\lambda}$. Thus, Bohr's required quantized angular-momentum condition, $mvr = \frac{nh}{2\pi}$, can be written $\frac{hr}{\lambda} = \frac{nh}{2\pi}$ or $2\pi r = n\lambda$.

Figure 25 illustrates this relationship that the circumference of the Bohr orbit ($2\pi r$) must be equal to a whole number multiple (n) of de Broglie wavelengths (λ).

Given	Green λ < Red λ → Green photons have higher energy
Step 1	**CYP 47 & 48:** 47: Worked only for hydrogen (failed for helium/multi-electron atoms) and couldn't explain why stationary states don't radiate. 48: **Yes**, green (higher *E*) can pump red; **No**, red (lower *E*) cannot pump green.
Step 2	**CYP 49 & 50:** 49: **Coherent, monochromatic, directional, intense**. 50: Shrinking Δ*x* to nuclear size forces huge Δ*p* (Heisenberg), giving the electron enormous kinetic energy.
Answer	**All Q16 conceptual & laser answers complete**

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FRQ Q20

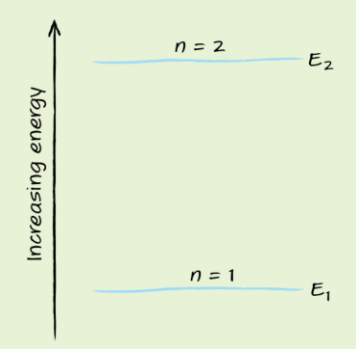
FRQ · FREE RESPONSE

Calculate atomic energy changes, emitted/absorbed photon wavelengths, and hydrogen orbital radii/energies.

pp. 72–74 · E.P(4,5) P.P(37–39) · C.Y.P(42) 8–11 marks

EXAMPLE PROBLEM 4 **FRQ · FREE RESPONSE** Student Book p. 72

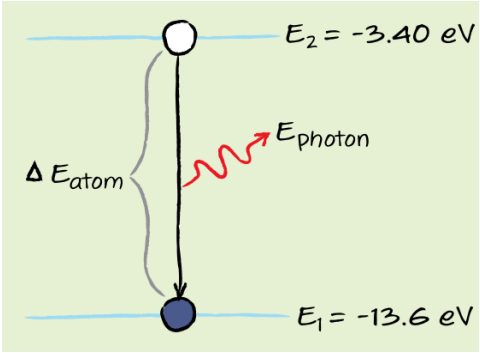
To move a hydrogen electron from $n = 1$ to $n = 2$, the atom must absorb energy. Determine E_1, E_2, and the energy absorbed.



Given	$E_n = -13.6 \text{ eV} / n^2$
Step 1	**Energy levels E_1 and E_2:** $E_1 = \frac{-13.6}{1^2} =$ **−13.6 eV**; $E_2 = \frac{-13.6}{2^2} =$ **−3.40 eV**
Step 2	**Energy absorbed:** $\Delta E = E_2 - E_1 = -3.40 - (-13.6) =$ **10.2 eV**
Answer	**$E_1 = -13.6$ eV; $E_2 = -3.40$ eV; $\Delta E = 10.2$ eV**

EXAMPLE PROBLEM 5 **FRQ · FREE RESPONSE** Student Book p. 73

An excited hydrogen electron drops from $n = 2$ to $n = 1$. Calculate the energy, frequency, and wavelength of the emitted photon.



Given	$E_2 = -3.40$ eV, $E_1 = -13.6$ eV
Step 1	**Photon energy:** $E_{photon} = E_2 - E_1 = -3.40 - (-13.6) =$ **10.2 eV** $(1.63 \times 10^{-18}$ J)
Step 2	**Frequency & Wavelength:** $f = \dfrac{1.63 \times 10^{-18}\ \text{J}}{6.63 \times 10^{-34}\ \text{J·s}} =$ **2.46×10^{15} Hz**; $\lambda = \dfrac{1240\ \text{eV·nm}}{10.2\ \text{eV}} =$ **122 nm** (UV)
Answer	**10.2 eV; 2.46×10^{15} Hz; 122 nm**

PRACTICE PROBLEMS 37, 38 & 39 **FRQ · FREE RESPONSE** Student Book p. 73

37. Find the wavelengths emitted for transitions $n = 3 \rightarrow 2$ (P.P 34: 1.89 eV) and $n = 4 \rightarrow 2$ (P.P 35: 2.55 eV) and match them to Figure 18.

38. A mercury atom drops from 8.82 eV to 6.67 eV; find emitted photon energy and wavelength.

39. CHALLENGE: A He^+ ion drops to its ground state (−54.4 eV) emitting a 304-nm photon; find the excited state energy.

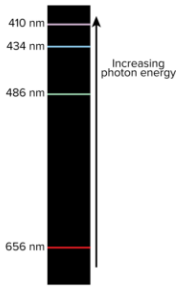


Figure 18 Hydrogen's emission spectrum has four lines in the visible range.

Given	$E = 1240$ eV·nm / λ
Step 1	**Problem 37 (Balmer lines):** $3 \rightarrow 2$: $\lambda = \frac{1240}{1.89} =$ **656 nm** (red); $4 \rightarrow 2$: $\lambda = \frac{1240}{2.55} =$ **486 nm** (blue-green)
Step 2	**Problem 38 (Mercury):** $E_{photon} = 8.82 - 6.67 =$ **2.15 eV**; $\lambda = \frac{1240}{2.15} =$ **577 nm**
Step 3	**Problem 39 (He^+ ion):** $E_{photon} = \frac{1240}{304} = 4.08$ eV $\rightarrow$ $E_{excited} = -54.4 + 4.08 =$ **−50.3 eV**
Answer	**37) 656 nm, 486 nm | 38) 2.15 eV, 577 nm | 39) −50.3 eV**

PRACTICE · YOUR TURN **FRQ · FREE RESPONSE** 3 Free-Response questions on FRQ Q20 — rising in difficulty

1 RECALL

Write the equation for the total energy of an electron in the *n*th orbit of hydrogen, and name the series for transitions ending at $n = 1$, 2, and 3.

Step 1	**Equation & Series:** $E_n = \frac{-13.6 \text{ eV}}{n^2}$; n=1: **Lyman (UV)**; n=2: **Balmer (Visible)**; n=3: **Paschen (IR)**.
Answer	**$E_n = -13.6/n^2$ eV; Lyman, Balmer, Paschen**

2 APPLY

An electron in hydrogen drops from $n = 5$ ($E_5 = -0.544$ eV) to $n = 2$ ($E_2 = -3.40$ eV). Find the emitted photon's energy and wavelength.

Given	$E_5 = -0.544$ eV, $E_2 = -3.40$ eV
Step 1	**Energy & Wavelength:** $E = -0.544 - (-3.40) =$ **2.86 eV** $\rightarrow \lambda = \frac{1240}{2.856} =$ **434 nm** (violet-blue)
Answer	**2.86 eV; 434 nm**

3 CHALLENGE

A hydrogen atom in the $n = 1$ ground state absorbs a 102.6-nm UV photon. Determine the energy of the excited state and its principal quantum number n.

Given	$E_1 = -13.6$ eV, $\lambda = 102.6$ nm
Step 1	**Absorbed energy & final level:** $E_{photon} = \frac{1240}{102.6} = 12.09$ eV $\rightarrow E_n = -13.6 + 12.09 =$ **−1.51 eV**
Step 2	**Quantum number n:** $n = \sqrt{\frac{-13.6}{-1.51}} =$ **3**
Answer	**$E_3 = -1.51$ eV; $n = 3$**