HOLIDAY HOMEWORK 假期作业

AP Physics 2

Exercise sheets and past-paper practice, topic by topic.

每个单元：练习卷 + 历年真题。

For class or self-study • no answer keys included.

Contents 目录

9 Temperature, gases, and heat – Part 1

Name: ____________ Class: ________ Date: __________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
Thermodynamics	热力学			
kinetic theory	分子运动论			
Temperature	温度			
pressure	压强			
ideal gas	理想气体			
Heat	热量			
thermal equilibrium	热平衡			
conduction	传导			
convection	对流			
radiation	辐射			
specific heat	比热容			

Recall

You already know a lot about heat and gases:

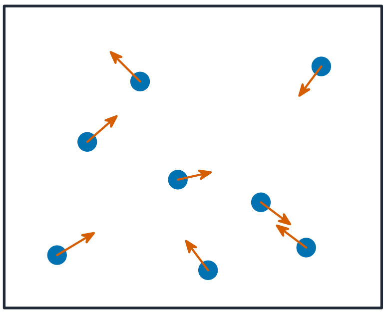
- Hot things feel hot because their tiny particles move fast; cold things move slowly.
- A gas pushes out on its container – a balloon stays full because the air pushes on it.
- Heat always flows from the hot object to the cold one, never the other way.

This sheet gives these ideas exact formulas. Each idea has a worked example.

New ideas

■ 1 Temperature and moving particles

Thermodynamics 热力学 is the study of heat and energy in large groups of particles. The **kinetic theory** 分子运动论 says a gas is countless tiny particles in fast, random motion.



1. many identical molecules, in continuous **random motion**
2. their own volume is **tiny** next to the container
3. straight lines between hits - intermolecular forces **ignored**
4. collisions are **elastic**: no kinetic energy is lost

poor at very high pressure (volume matters) or very low temperature (forces matter)

Temperature 温度 measures the **average kinetic energy** of those particles: hotter means faster-moving. The **pressure** 压强 a gas makes comes from its particles hitting the container walls.

■ 2 The ideal gas law

An **ideal gas** 理想气体 obeys

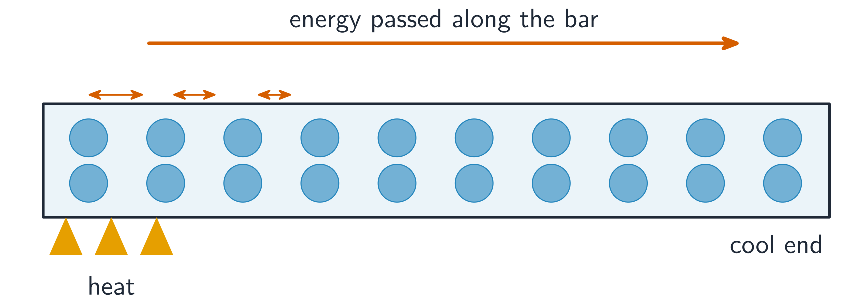
$$PV = nRT,$$

linking pressure P, volume V, amount n, and temperature T (always in **kelvin**). Change one quantity and the law tells you how another responds.

Worked example. A sealed rigid can of gas is at 1.0×10^5 Pa and 300 K. Heated to 450 K at fixed volume, $\dfrac{P}{T}$ stays constant, so $P_2 = P_1\dfrac{T_2}{T_1} = 1.0 \times 10^5 \times \dfrac{450}{300} = 1.5 \times 10^5$ Pa.

■ 3 Heat and how it moves

Heat 热量 Q is energy that flows because of a temperature difference – always from hot to cold. When two objects reach the same temperature they are in **thermal equilibrium** 热平衡 and the flow stops. Heat travels by **conduction** 传导 (through solids), **convection** 对流 (moving fluids), and **radiation** 辐射 (waves, even through empty space).



particles vibrate more at the hot end and pass the energy to their neighbours

■ 4 Specific heat

The **specific heat** 比热容 c is the heat needed to warm 1 kg of a substance by 1 °C:

$$Q = mc\,\Delta T.$$

Worked example. Heating 2.0 kg of water ($c = 4200$) from 20 °C to 80 °C needs $Q = mc\,\Delta T = 2.0 \times 4200 \times 60 = 5.0 \times 10^5$ J.

Watch out: always convert temperatures to **kelvin** ($T_\mathrm{K} = T_\mathrm{C} + 273$) before using a gas law – using Celsius gives nonsense.

Practice

Try these in order. The methods are all above.

2.1 State what temperature measures, in terms of the particles of a gas. [1]

2.2 Convert 27 °C to kelvin. [1]

2.3 A rigid can of gas at 2.0×10^5 Pa and 300 K is cooled to 150 K. Find the new pressure. [3]

2.4 Name the three ways heat can travel, and give the one that works through empty space. [2]

2.5 How much heat warms 0.50 kg of water ($c = 4200$) by 30 °C? [2]

2.6 Explain why coastal towns have milder temperatures than inland ones (think about water's specific heat). [2]

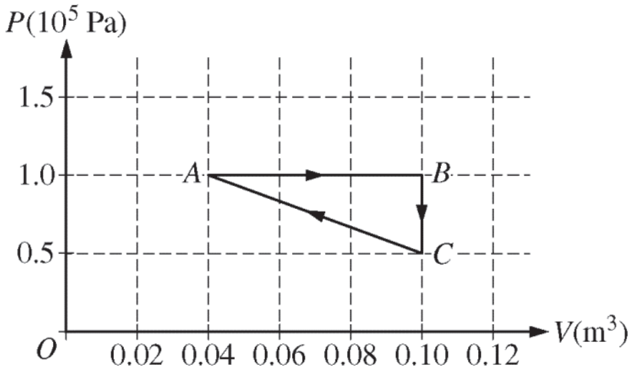
PHYSICS 2

Section II

4 Questions

Time—90 minutes

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)

   Two moles of a monatomic ideal gas are enclosed in a cylinder by a movable piston. The gas is taken through the thermodynamic cycle shown in the figure above. The piston has a cross-sectional area of $5 \times 10^{-3}\ \text{m}^2$.

   (a)

   i. Calculate the force that the gas exerts on the piston in state *A*, and explain how the collisions of the gas atoms with the piston allow the gas to exert a force on the piston.

   ii. Calculate the temperature of the gas in state *B*, and indicate the microscopic property of the gas that is characterized by the temperature.

   (b)

   i. Predict qualitatively how the internal energy of the gas changes as it is taken from state *A* to state *B*. Justify your prediction.

   ii. Calculate the energy added to the gas by heating as it is taken from state *A* to state *C* along the path *ABC*.

   (c) Determine the change in the total kinetic energy of the gas atoms as the gas is taken directly from state *C* to state *A*.

PHYSICS 2

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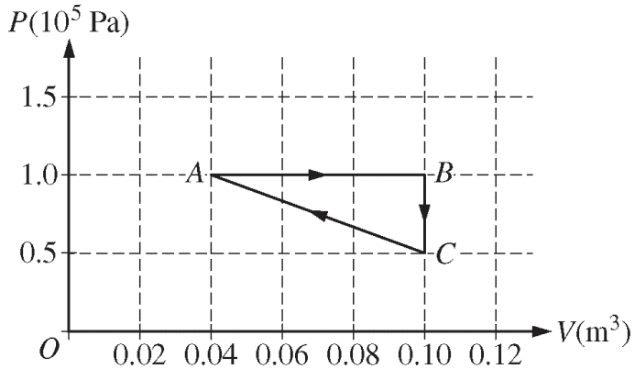

1. (10 points, suggested time 20 minutes)

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   i. Calculate the force that the gas exerts on the piston in state *A*, and explain how the collisions of the gas atoms with the piston allow the gas to exert a force on the piston.

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   ii. Calculate the energy added to the gas by heating as it is taken from state *A* to state *C* along the path *ABC*.

   (c) Determine the change in the total kinetic energy of the gas atoms as the gas is taken directly from state *C* to state *A*.

9 The laws of thermodynamics – Part 2

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
internal energy	内能			
first law of thermodynamics	热力学第一定律			
Entropy	熵			
second law of thermodynamics	热力学第二定律			

Recall

In Part A you met temperature, gases, and heat. Now connect heat to energy:

- Energy is never lost – it only moves or changes form (you saw this with work and kinetic energy).
- Heating a gas can warm it **or** make it push out and do work.
- Heat only ever flows hot → cold on its own. This sheet says why.

Each idea has a worked example before the Practice.

New ideas

■ 1 Internal energy

The **internal energy** 内能 U of a gas is the total energy of its particles' motion. More internal energy means a higher temperature.

■ 2 The first law of thermodynamics

The **first law of thermodynamics** 热力学第一定律 is just energy conservation for a gas:

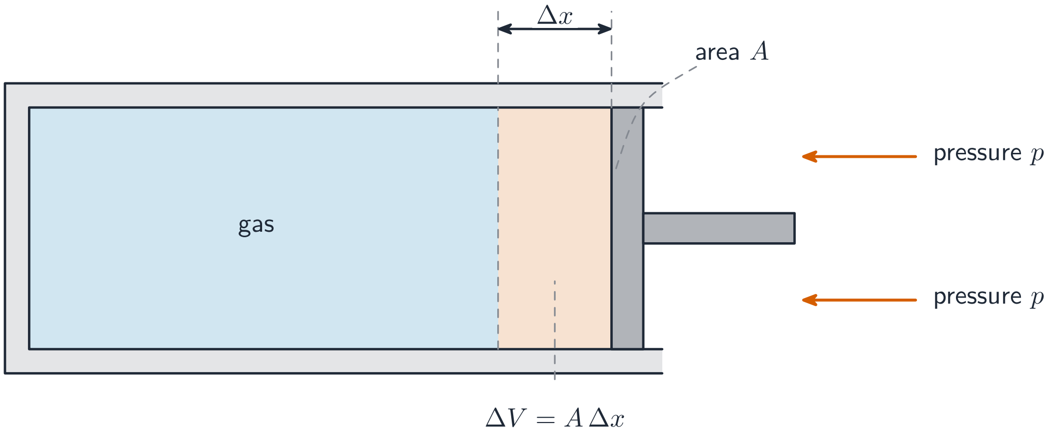
$$\Delta U = Q + W,$$

where Q is the heat added **to** the gas and W is the work done **on** the gas. Add heat and the gas warms up or does work (or both).

Worked example. A gas absorbs 500 J of heat and does 200 J of work on its surroundings (so work done **on** the gas is $W = -200$ J): $\Delta U = Q + W = 500 + (-200) = 300$ J. Its internal energy rises by 300 J, so it ends up hotter.

■ 3 Work when a gas expands

When a gas expands and pushes a piston, it does work on the outside world.



Compressing a gas does **positive** work on it (raising its energy); letting it expand does **negative** work on it (it gives energy away).

■ 4 Entropy and the second law

Entropy 熵 measures how spread-out or disordered energy is. The **second law of thermodynamics** 热力学第二定律 says the total entropy of an isolated system never decreases – energy naturally spreads out. This is why heat flows hot → cold by itself, and never cold → hot.

Watch out: in $\Delta U = Q + W$, the sign of W matters most. Work done **on** the gas is positive; when the gas does work on its surroundings, W is **negative**. Get the sign right and these problems are easy.

Practice

Try these in order. The methods are all above.

2.1 State what the internal energy of a gas depends on. [1]

2.2 A gas gains 400 J of heat and 100 J of work is done **on** it. Find the change in internal energy. [2]

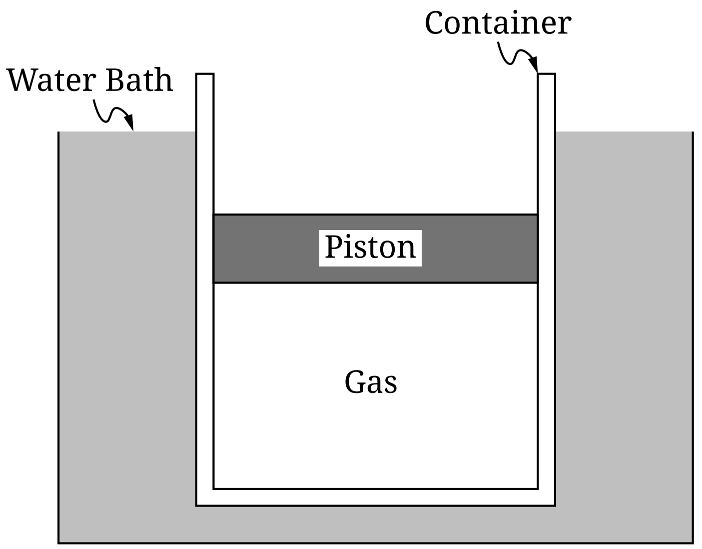
2.3 A gas absorbs 600 J of heat and does 250 J of work on its surroundings. Find the change in its internal energy. [3]

2.4 State the direction heat naturally flows between a hot and a cold object, and name the law that sets this direction. [2]

2.5 Explain why energy naturally spreads out rather than gathering into one place, using the idea of entropy. [2]

Question 2: Version J

2. A sample of a monatomic ideal gas is sealed in a thermally conducting container by a movable piston of mass M and area A. The container is in a large water bath that is held at a constant temperature T_0. The piston is free to move with negligible friction. At the instant shown, the gas is in thermal equilibrium with the water bath, the piston is at rest, and the gas occupies volume V_0. The pressure of the air above the piston is P_{atm}.



Side View

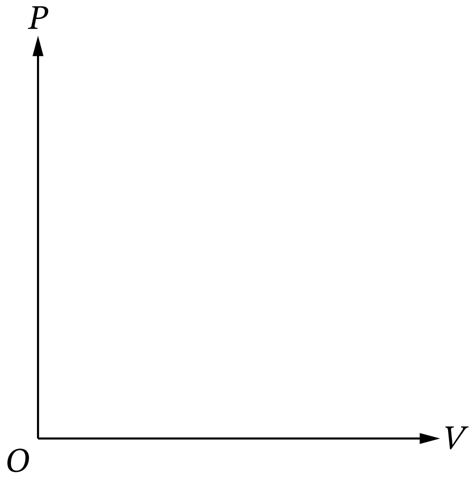
Note: Figure not drawn to scale.

A. On the dot shown, representing the piston, **draw** and **label** the forces that are exerted on the piston. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

B. **Derive** an expression for the internal energy of the gas in terms of M, A, V_0, P_{atm}, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. A block, also of mass M, is placed on the piston at time $t = t_0$ and is slowly lowered. The piston comes to rest at $t = t_f$ when the block is completely released.

On the axes provided, **sketch** the expected relationship between the pressure P and volume V of the gas for the thermodynamic process that the gas undergoes during time interval $t_0 \leq t \leq t_f$. **Draw** an arrow on your sketch to represent the direction of the thermodynamic process.



D. With the block still on the piston, the temperature of the water bath is changed to a new constant temperature T_{new}. The gas occupies the original volume V_0 when the sample of gas and the water bath come to thermal equilibrium.

Indicate whether T_{new} is greater than, less than, or equal to T_0.

______ $T_{new} > T_0$

______ $T_{new} < T_0$

______ $T_{new} = T_0$

Briefly **justify** your answer by referencing at least one feature of your answers to parts A, B, or C.

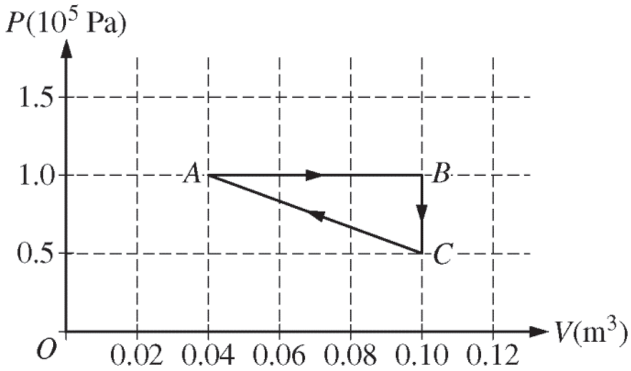
PHYSICS 2

Section II

4 Questions

Time—90 minutes

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)

   Two moles of a monatomic ideal gas are enclosed in a cylinder by a movable piston. The gas is taken through the thermodynamic cycle shown in the figure above. The piston has a cross-sectional area of 5×10^{-3} m^2.

   (a)

   i. Calculate the force that the gas exerts on the piston in state *A*, and explain how the collisions of the gas atoms with the piston allow the gas to exert a force on the piston.

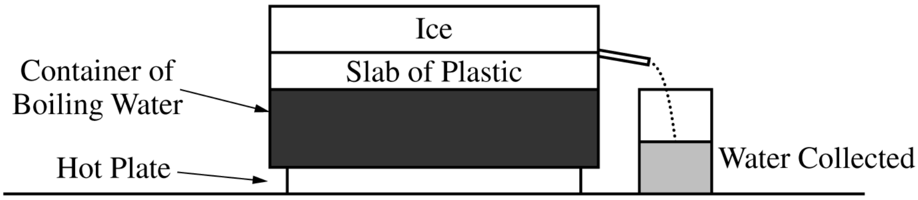
   ii. Calculate the temperature of the gas in state *B*, and indicate the microscopic property of the gas that is characterized by the temperature.

   (b)

   i. Predict qualitatively how the internal energy of the gas changes as it is taken from state *A* to state *B*. Justify your prediction.

   ii. Calculate the energy added to the gas by heating as it is taken from state *A* to state *C* along the path *ABC*.

   (c) Determine the change in the total kinetic energy of the gas atoms as the gas is taken directly from state *C* to state *A*.



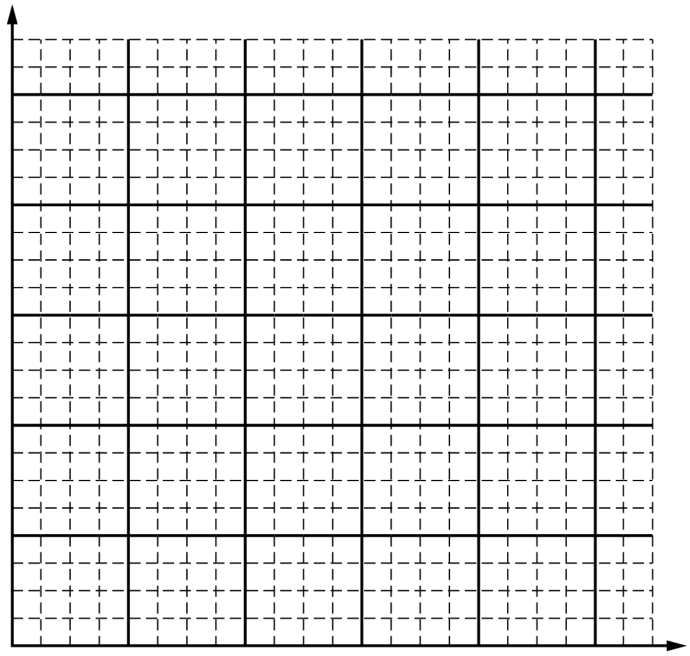
3. (12 points, suggested time 25 minutes)

A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of $100°C$. They place a slab of the plastic with area $0.025\ m^2$ and thickness 0.010 m above the container so that the bottom surface of the slab is at a temperature of $100°C$. They put a large block of ice with temperature $0°C$ on top of the plastic slab. Some of the ice melts, and the students measure the amount of water collected during a time Δt. The students correctly calculate the amount of energy Q delivered to the ice and thus determine $Q/\Delta t$. They repeat this experiment several times, each time adding an identical slab to increase the total thickness L of plastic. Their results are shown in the table below.

Energy flow rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total thickness of plastic L (m)	0.010	0.020	0.030	0.040	0.050

(a) The students want to create a graph to yield a straight line whose slope could be used to calculate the thermal conductivity of the plastic.

i. Label the axes below to indicate a pair of quantities that could be graphed to yield a straight line. Include units for the quantities.



ii. On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following.

- Add to the data table the values of any quantities to be plotted that are not already given.
- Scale the axes.
- Plot the data from the table.
- Draw a line that best represents the data.

iii. Use the graph to calculate the thermal conductivity of the plastic.

(b) Indicate one potential problem with the setup that could lead to an experimental value for the thermal conductivity that is different from the actual value. Use physics principles to explain the effect this problem could have on the experimental value.

(c) The rectangle below represents a side view of the plastic slab. Draw a single arrow on the diagram representing the direction of the net flow of energy through the plastic.

(d) Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).

(e) An extra plastic slab sits on a wood surface, with both the plastic slab and the wood surface at room temperature. A student touches each and finds that the plastic slab feels cooler than the wood surface. Explain what causes this observation.

10 Electric charge, force, and field – Part 1

Name: ____________ Class: ________ Date: __________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Electric charge	电荷			
Coulomb's law	库仑定律			
conductor	导体			
insulator	绝缘体			
conduction	接触起电			
induction	感应起电			
electric field	电场			

Recall

You have already seen electric charge in action:

- Rub a balloon on your hair and it sticks to the wall – that is static electricity.
- Like charges push apart; opposite charges pull together.
- A metal wire lets charge flow; plastic does not.

This sheet makes the force between charges exact. Each idea has a worked example.

New ideas

1 Electric charge

Electric charge 电荷 comes in two kinds, positive and negative. Like charges **repel**, opposite charges **attract**. Charge is carried by electrons moving from one object to another.

2 Coulomb's law

The force between two point charges is **Coulomb's law** 库仑定律:

$$F = \frac{kq_1q_2}{r^2},$$

with $k = 9.0 \times 10^9$. Like gravity it is an inverse-square law, but it can push **or** pull.

Worked example. Two charges of 3.0 μC and 2.0 μC sit 0.10 m apart: $F = \dfrac{9.0 \times 10^9 \times (3.0 \times 10^{-6})(2.0 \times 10^{-6})}{(0.10)^2} = 5.4$ N.

3 Conductors, insulators, and charging

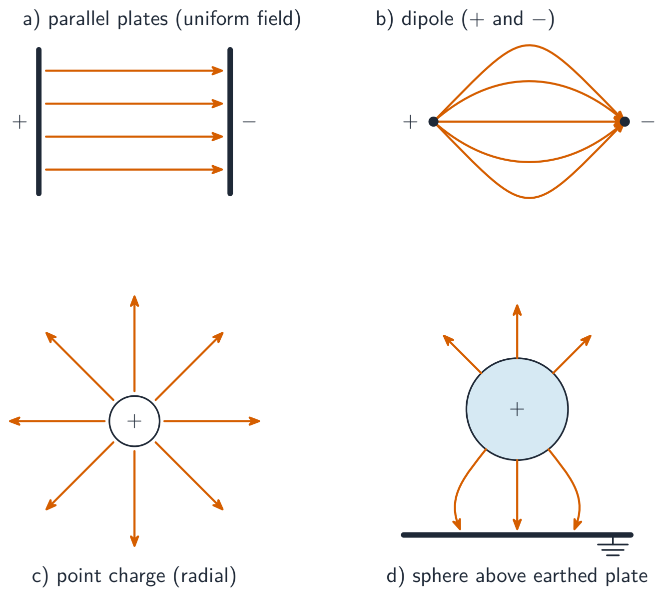
A **conductor** 导体 lets charge move freely (metals); an **insulator** 绝缘体 holds it in place (plastic, rubber). Objects charge up by **friction** (rubbing), by **conduction** 接触起电 (touching), or by **induction** 感应起电 (a nearby charge pushes charge around inside a neutral object).

4 The electric field

An **electric field** 电场 E is the force felt per unit of charge:

$$E = \frac{F}{q}, \qquad \text{so a charge in a field feels} \qquad F = qE.$$

Field lines point away from positive charges and toward negative ones.



Worked example. A field of 2000 N/C acts on a 3.0×10^{-6} C charge: $F = qE = 3.0 \times 10^{-6} \times 2000 = 6.0 \times 10^{-3}$ N.

> **Watch out:** Coulomb's law is inverse-square – **doubling** the distance makes the force **four times smaller**, not two times. Always square the distance.

Practice

Try these in order. The methods are all above.

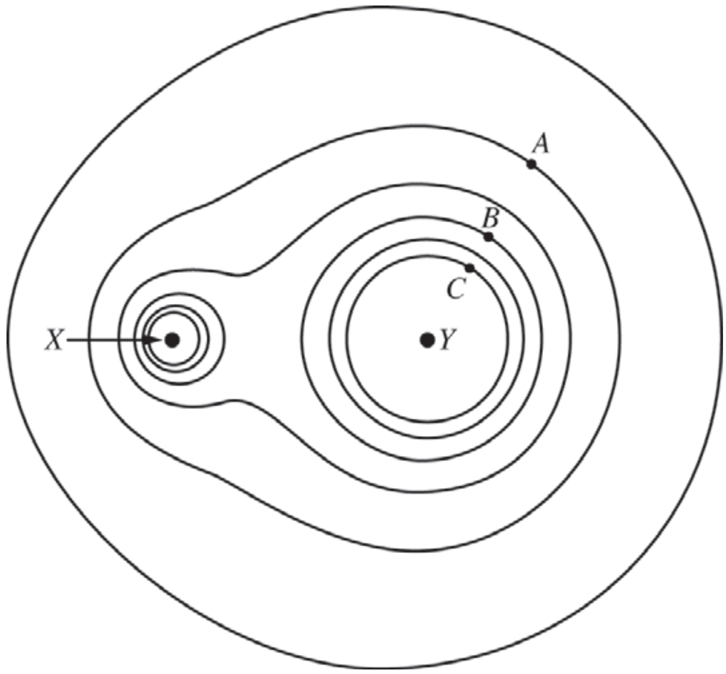
2.1 State whether the force is a push or a pull between (a) two positive charges, (b) a positive and a negative charge. [2]

2.2 Two charges of 4.0 μC and 1.0 μC are 0.20 m apart. Find the force between them ($k = 9.0 \times 10^9$). [3]

2.3 Give one example each of a good conductor and a good insulator. [2]

2.4 A field of 500 N/C acts on a 2.0×10^{-6} C charge. Find the force on it. [2]

2.5 Two charges are moved from 0.10 m apart to 0.20 m apart. State what happens to the force between them, and by what factor. [2]



3. (12 points, suggested time 25 minutes)

The dots in the figure above represent two identical spheres, *X* and *Y,* that are fixed in place with their centers in the plane of the page. Both spheres are charged, and the charge on sphere *Y* is positive. The lines are isolines of electric potential, also in the plane of the page, with a potential difference of 10 V between each set of adjacent lines. The absolute value of the electric potential of the outermost line is 50 V.

(a) Indicate the values of the potentials, including the signs, at the labeled points *A* and *B*.

Potential at point *A* _______ Potential at point *B* _______

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

ii. The spheres at points X and Y have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

Let the potentials at the three labeled points be V_A , V_B , and V_C . A proton with charge $+q$ and mass *m* is released from rest at point *B*.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

(d) At some time after being released from rest at point B, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of q, V_A, V_B, V_C, and physical constants, as appropriate.

ii. As it moved through the 20 V potential difference, the proton was displaced a distance d by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude E_{avg} of the electric field over that distance.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

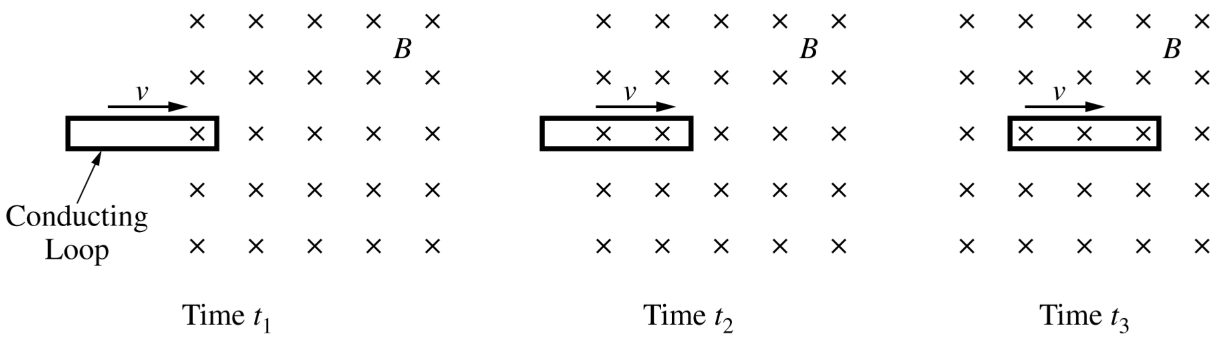
PHYSICS 2

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.

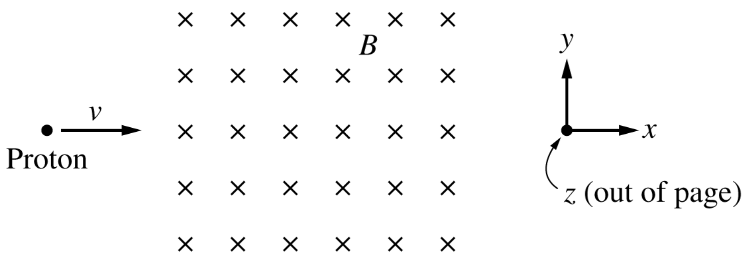


1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

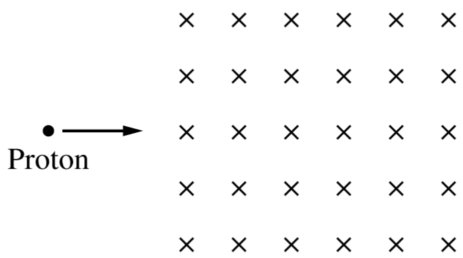
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



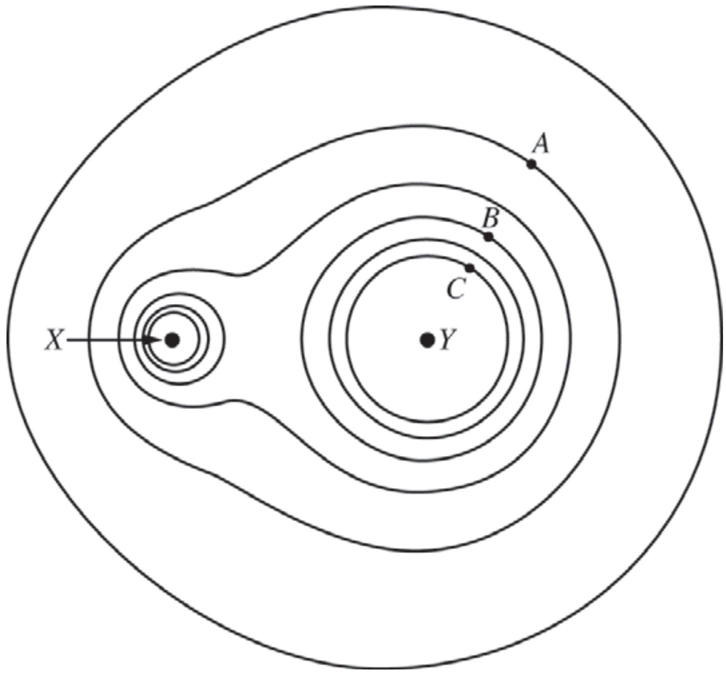
i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).



3. (12 points, suggested time 25 minutes)

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(a) Indicate the values of the potentials, including the signs, at the labeled points A and B.

Potential at point A _______ Potential at point B _______

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i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

ii. The spheres at points X and Y have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

Let the potentials at the three labeled points be V_A, V_B, and V_C. A proton with charge $+q$ and mass m is released from rest at point B.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

(d) At some time after being released from rest at point B, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of q, V_A, V_B, V_C, and physical constants, as appropriate.

ii. As it moved through the 20 V potential difference, the proton was displaced a distance d by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude E_{avg} of the electric field over that distance.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

10 Electric potential and capacitors – Part 2

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
Electric potential	电势			
voltage	电压			
capacitor	电容器			
capacitance	电容			

Recall

In Part A you met electric charge, force, and field. Now two ideas you use every day without noticing:

- **Voltage** is written on every battery (1.5 V, 9 V). It is really "electric potential."
- A **capacitor** stores charge – it is inside phones, cameras, and flashes.

Each idea has a worked example before the Practice.

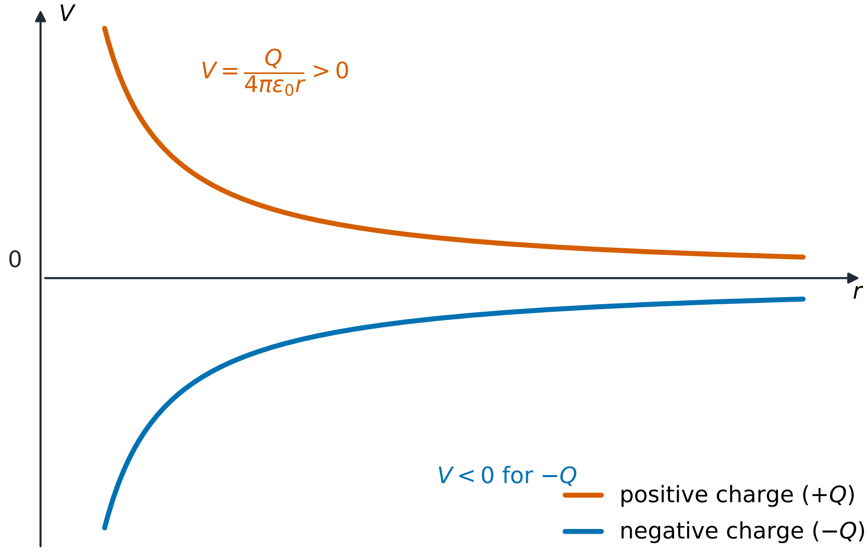
New ideas

■ 1 Electric potential

Electric potential 电势 V is the electric potential energy per unit charge, measured in volts:

$$V = \frac{U}{q}.$$

Unlike the field (a vector), potential is a simple number (a scalar), so it is easier to work with.



■ 2 Voltage

The **voltage** 电压 (potential difference) between two points is the work done per unit charge to move a charge between them: $U = qV$. A positive charge moves from high to low potential on its own – like a ball rolling downhill.

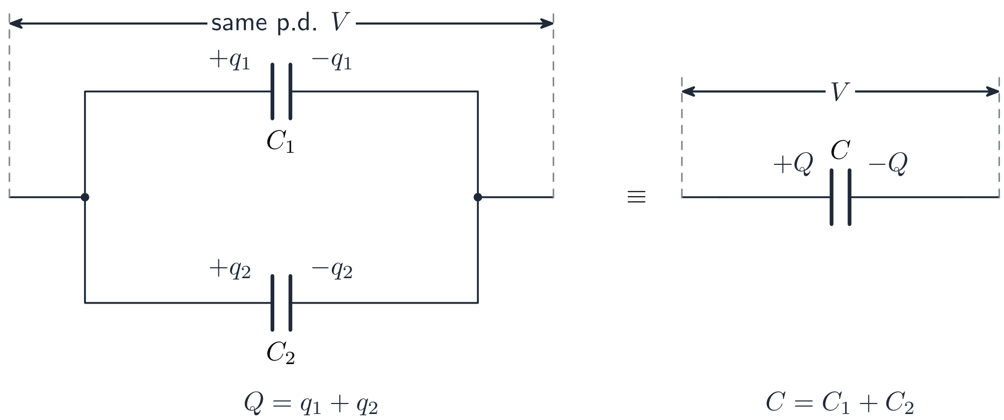
Worked example. Moving a charge of 2.0 C through a potential difference of 6.0 V transfers $U = qV = 2.0 \times 6.0 = 12$ J of energy.

■ 3 Capacitors

A **capacitor** 电容器 stores charge on two plates. Its **capacitance** 电容 links charge to voltage:

$$C = \frac{Q}{V},$$

and it stores energy $U = \frac{1}{2}CV^2$.



Worked example. A 100 μF capacitor charged to 12 V holds $Q = CV = 100 \times 10^{-6} \times 12 = 1.2 \times 10^{-3}$ C and stores $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 100 \times 10^{-6} \times 12^2 = 7.2 \times 10^{-3}$ J.

■ **4 Charges gain energy from voltage**

A charge released across a voltage speeds up, turning electric energy into kinetic energy:

$$qV = \tfrac{1}{2}mv^2.$$

Watch out: electric potential V is a **scalar** (just a number), so potentials from several charges simply **add** – much easier than adding field arrows, which are vectors.

Practice

Try these in order. The methods are all above.

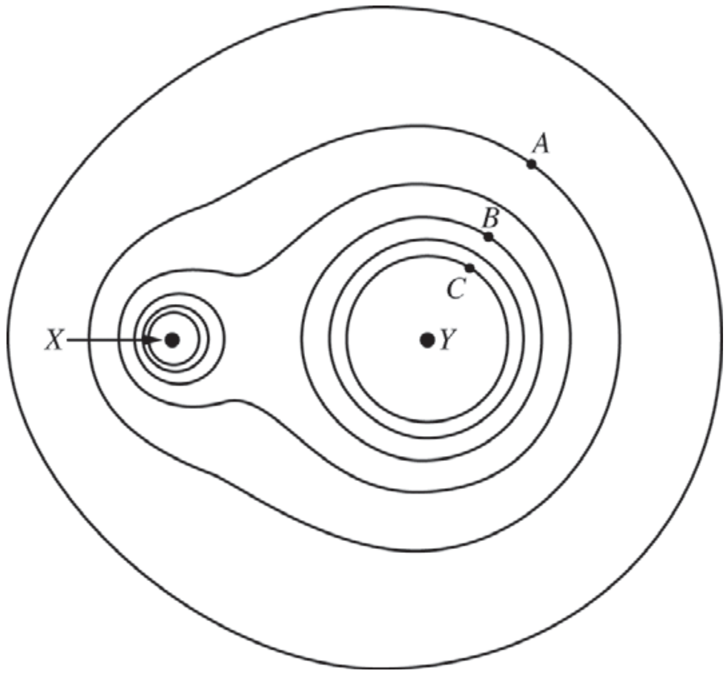
2.1 State what electric potential (voltage) measures, in words. [1]

2.2 Moving a 3.0 C charge through a potential difference of 4.0 V – find the energy transferred. [2]

2.3 A 50 μF capacitor is charged to 10 V. Find the charge it stores. [2]

2.4 For the capacitor in 2.3, find the energy stored ($U = \frac{1}{2}CV^2$). [3]

2.5 Explain why electric potential is easier to add up than the electric field, when several charges are present. [2]



3. (12 points, suggested time 25 minutes)

The dots in the figure above represent two identical spheres, X and Y, that are fixed in place with their centers in the plane of the page. Both spheres are charged, and the charge on sphere Y is positive. The lines are isolines of electric potential, also in the plane of the page, with a potential difference of 10 V between each set of adjacent lines. The absolute value of the electric potential of the outermost line is 50 V.

(a) Indicate the values of the potentials, including the signs, at the labeled points A and B.

Potential at point A _______ Potential at point B _______

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

ii. The spheres at points X and Y have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

Let the potentials at the three labeled points be V_A, V_B, and V_C. A proton with charge $+q$ and mass m is released from rest at point B.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

(d) At some time after being released from rest at point B, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of q, V_A, V_B, V_C, and physical constants, as appropriate.

ii. As it moved through the 20 V potential difference, the proton was displaced a distance d by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude E_{avg} of the electric field over that distance.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
- Student 2 says that if the system is defined as only the proton, the kinetic energy of the proton increases because positive work is done on the proton by the electric field as the proton moves through the 20 V potential difference.

Discuss each student's claims, explaining why each is correct or incorrect.

4. (10 points, suggested time 20 minutes)

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

(a)

i. Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.

ii. Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.

(b) The switch is opened, the capacitor is discharged, and a second, identical capacitor is added to the circuit in series with the other components. The switch is then closed again.

i. A long time after the switch is closed, the energy stored in the single capacitor in the original circuit is U_1 , and the total energy stored in the two capacitors in the new circuit is U_2 . Calculate the ratio U_1/U_2 .

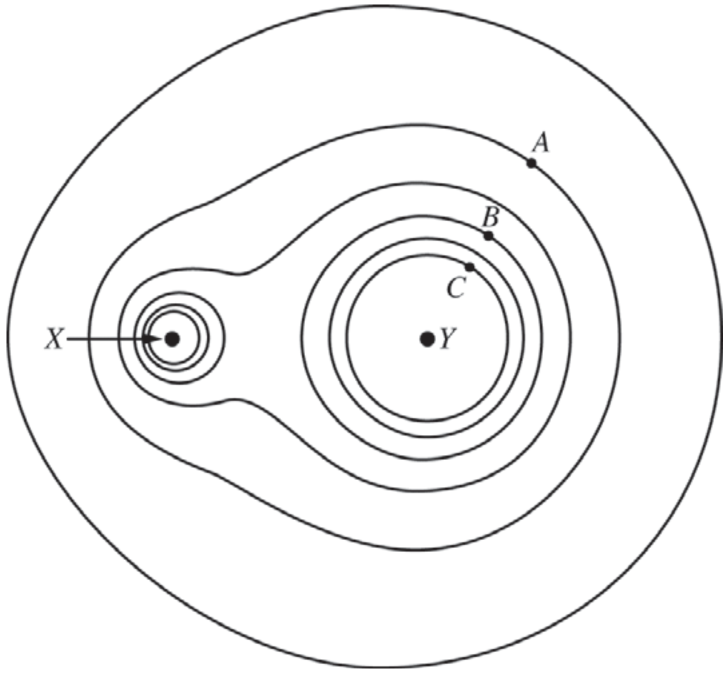
ii. The two capacitors in series are to be replaced with a single capacitor that will have the same energy U_2 . Indicate a plate area and a distance between the plates for the new capacitor, compared with one of the original capacitors, that will accomplish this. Support your reasoning using appropriate physics principles and/or mathematical models.

The students are then asked to design two circuits each containing a switch, a battery with a small internal resistance, a lightbulb, and a capacitor. In arrangement 1, the bulb should gradually light up after the switch is closed, becoming brightest after the switch has been closed a long time. In arrangement 2, the bulb should be brightest when the switch is first closed, getting dimmer with time, and going out completely when the switch has been closed for a long time.

(c) Using standard symbols, draw two circuit diagrams, one showing a possible circuit for arrangement 1 and the other showing a possible circuit for arrangement 2. Justify your circuit diagrams with a paragraph-length explanation referring to the properties of lightbulbs and capacitors in circuits and the conservation of energy and/or the conservation of charge.

STOP

END OF EXAM



3. (12 points, suggested time 25 minutes)

The dots in the figure above represent two identical spheres, X and Y, that are fixed in place with their centers in the plane of the page. Both spheres are charged, and the charge on sphere Y is positive. The lines are isolines of electric potential, also in the plane of the page, with a potential difference of 10 V between each set of adjacent lines. The absolute value of the electric potential of the outermost line is 50 V.

(a) Indicate the values of the potentials, including the signs, at the labeled points A and B.

Potential at point A ________ Potential at point B ________

(b)

i. How do the magnitudes and the signs of the charges of the spheres compare? Explain your answer in terms of the isolines of electric potential shown.

ii. The spheres at points X and Y have masses in the same ratio as the magnitudes of their charges. The isolines of gravitational potential for the spheres have shapes similar to those of the isolines shown. Explain why the two sets of isolines have similar shapes.

Let the potentials at the three labeled points be V_A, V_B, and V_C. A proton with charge $+q$ and mass m is released from rest at point B.

(c) Based on your answer to part (b)(ii), briefly describe one similarity and one difference between the electric and gravitational forces exerted on the proton by the system of the two spheres. The similarity and difference you describe must not be ones that generally apply to all forces.

(d) At some time after being released from rest at point B, the proton has moved through a potential difference of magnitude 20 V.

i. Determine the change in electric potential energy of the proton-spheres system when the proton has moved through the 20 V potential difference. Express your answer symbolically in terms of q, V_A , V_B , V_C , and physical constants, as appropriate.

ii. As it moved through the 20 V potential difference, the proton was displaced a distance d by the electric force. Determine a symbolic expression for the total work done on the proton by the electric field in terms of the average magnitude E_{avg} of the electric field over that distance.

iii. Two students are discussing how and why the kinetic energy of the proton would change after it is released.

- Student 1 says that if the system is defined as the proton and the spheres, the increase in the proton's kinetic energy is due to a change in the system's potential energy as the proton moves through the 20 V potential difference.
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Discuss each student's claims, explaining why each is correct or incorrect.

11 Current, resistance, and power – Part 1

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Electric current	电流			
amperes	安培			
series	串联			
parallel	并联			
Resistance	电阻			
Ohm's law	欧姆定律			
Electric power	电功率			

Recall

You have built simple circuits before:

- A battery pushes a **current** around a loop of wire to light a bulb.
- More **voltage** pushes a bigger current; more **resistance** holds it back.
- You have wired bulbs in a line (series) and side by side (parallel).

This sheet lines these ideas up with exact formulas. Each idea has a worked example.

New ideas

1 Electric current

Electric current 电流 is the rate at which charge flows past a point, measured in **amperes** 安培 (A):

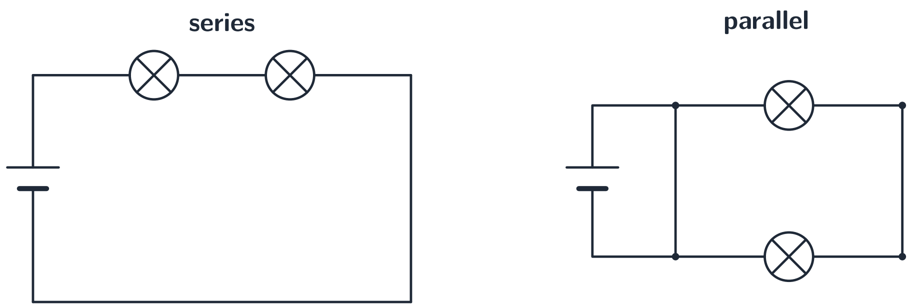
$$I = \frac{\Delta q}{\Delta t}.$$

A current needs a complete loop and a source (a battery) to push it.

Worked example. If 6.0 C of charge flows past a point in 3.0 s, the current is $I = \frac{\Delta q}{\Delta t} = \frac{6.0}{3.0} = 2.0$ A.

2 Series and parallel

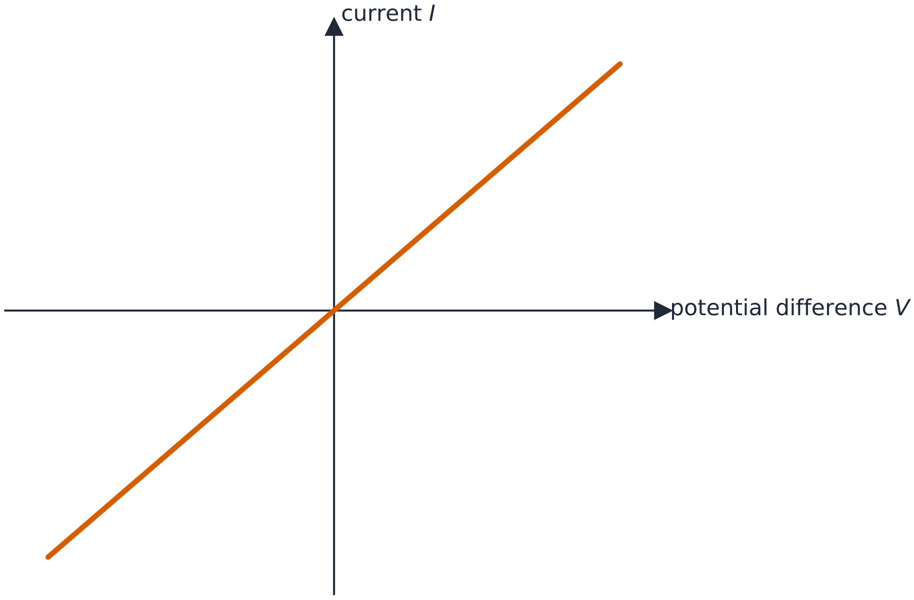
- In a **series** 串联 circuit the components are in one line, so the **same current** flows through each.
- In a **parallel** 并联 circuit they sit on separate branches, so the **same voltage** is across each.



3 Resistance and Ohm's law

Resistance 电阻 R (in ohms) opposes the current. **Ohm's law** 欧姆定律 links voltage, current, and resistance:

$$V = IR.$$



Worked example. A 2.0 A current through a 6.0 Ω resistor needs a voltage $V = IR = 2.0 \times 6.0 = 12$ V.

■ 4 Electric power

Electric power 电功率 is the rate a component turns electrical energy into heat, light or motion:

$$P = IV = I^2R = \frac{V^2}{R}.$$

Pick the form that uses what you know.

Worked example. The 6.0 Ω resistor carrying 2.0 A uses $P = I^2R = 2.0^2 \times 6.0 = 24$ W.

Watch out: in **series** the current is the same everywhere; in **parallel** the **voltage** is the same across each branch. Mixing these up is the most common circuit mistake.

Practice

Try these in order. The methods are all above.

2.1 A charge of 10 C flows past a point in 5.0 s. Find the current. [2]

2.2 State what is the same for every component in (a) a series circuit, (b) a parallel circuit. [2]

2.3 A 3.0 A current flows through a 4.0 Ω resistor. Find the voltage across it. [2]

2.4 A resistor carries 0.50 A with 6.0 V across it. Find the power it uses. [2]

2.5 A 12 V battery drives a current of 2.0 A through a bulb. Find the bulb's resistance and its power. [3]

2. (12 points, suggested time 25 minutes)

A group of students is given several long, thick, cylindrical conducting rods of the same unknown material with various lengths and diameters and asked to experimentally determine the resistivity of the material using a graph. The available equipment includes a voltmeter, an ammeter, connecting wires, a variable-output DC power supply, and a metric ruler.

(a)

i. Describe a procedure the students could use to collect the data needed to create the graph, including the measurements to be taken and a labeled diagram of the circuit to be used. Include enough detail that another student could follow the procedure and obtain similar data.

Draw a labeled diagram here.

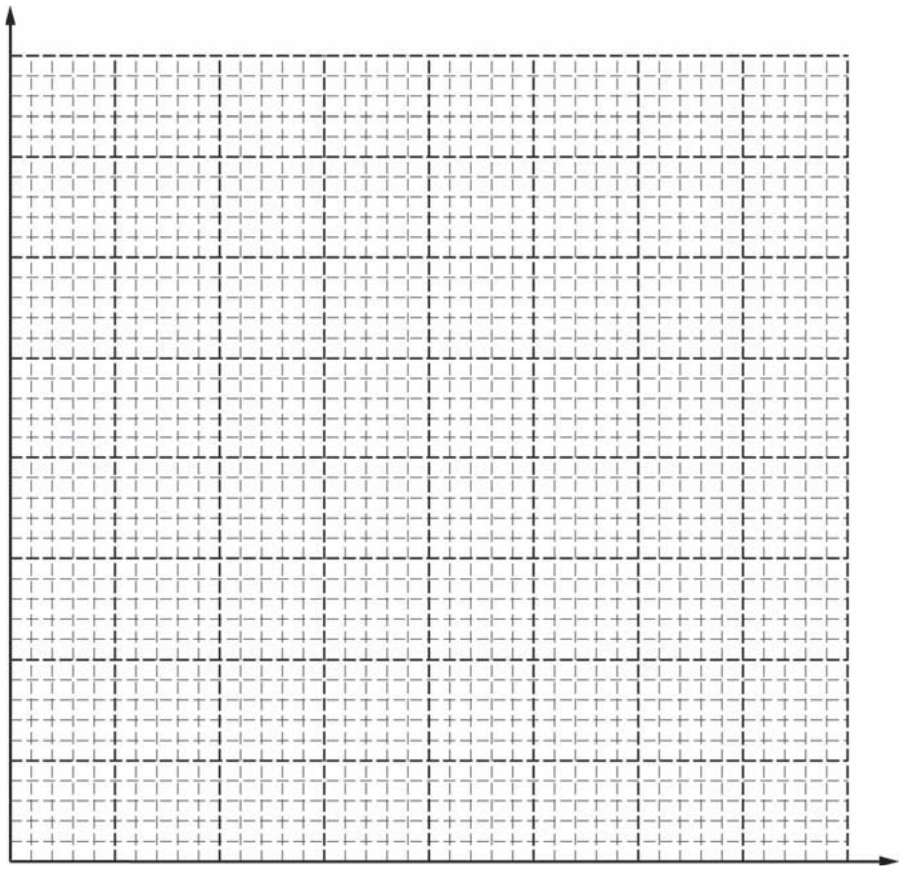
Write your procedure here.

ii. Describe how the data could be graphed in a way that is useful for determining the resistivity of the material. Describe how the graph could be analyzed to calculate the resistivity.

The students are now given a rectangular rod of the material, as shown below, whose dimensions are not known. The students are asked to experimentally determine the resistance of the rod. They obtain the data in the table below for the potential difference ΔV across the rod and the current I in it.

ΔV (V)	6.0	5.0	3.5	2.5	2.0	1.5
I (A)	0.078	0.070	0.044	0.036	0.027	0.018

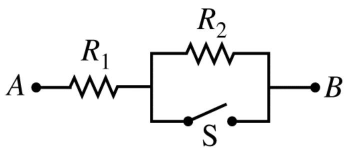
(b) On the axes below, plot the data so that the resistance of the rectangular rod can be determined from a best-fit line. Label and scale the axes. Use the best-fit line to determine the resistance of the rod, clearly showing your calculations.



(c) After completing their calculations, the students begin to consider the factors that might have produced uncertainties in their results.

i. The students realize that they did not take into account the internal resistance of the power supply. Briefly describe how this would affect their value of the resistance of the rectangular rod. Explain your reasoning.

ii. The students realize that they did not take into account a possible change in the temperature of the cylindrical rods. Should the students be concerned about this? Explain why or why not.



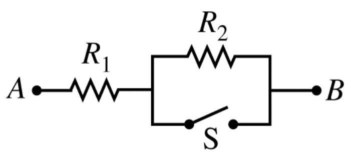
2. (12 points, suggested time 25 minutes)

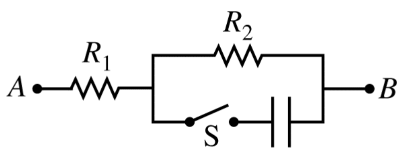
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram

Describe the Experiment





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

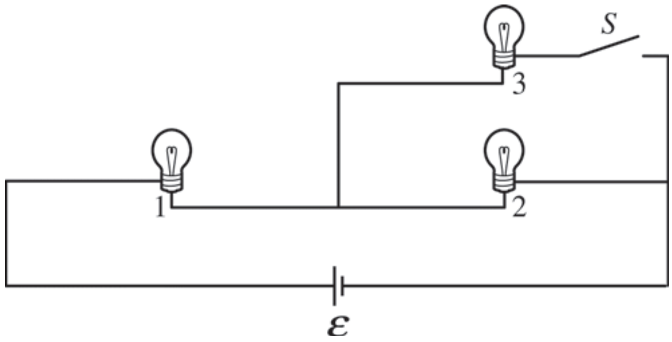
i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.



2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

11 Combining resistors and circuit rules – Part 2

Name: ____________ Class: ________ Date: __________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
equivalent resistance	等效电阻			
Kirchhoff's junction rule	基尔霍夫电流定律			
Kirchhoff's loop rule	基尔霍夫电压定律			

Recall

In Part A you used $V = IR$ and $P = IV$ for single components. Now handle circuits with **several** resistors:

- Resistors in a line add up; resistors side by side share the current.
- Whatever current flows into a junction must flow out again.

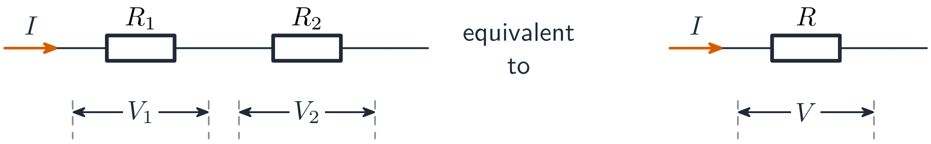
Each idea has a worked example before the Practice.

New ideas

1 Combining resistors

Replace several resistors with one **equivalent resistance** 等效电阻:

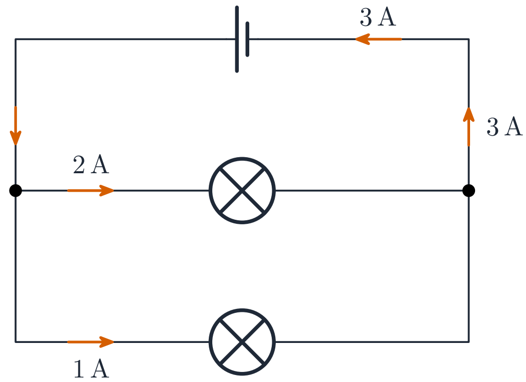
- **Series:** $R_{eq} = R_1 + R_2 + \cdots$ (they add).
- **Parallel:** $\dfrac{1}{R_{eq}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \cdots$ (the total is **less** than the smallest one).



Worked example. A 4.0 Ω and a 12 Ω resistor in **parallel**: $\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{12} = \frac{4}{12}$, so $R_{eq} = 3.0\ \Omega$ – smaller than either one.

■ 2 The junction rule

Kirchhoff's junction rule 基尔霍夫电流定律 says the current flowing **into** a junction equals the current flowing **out** (charge is conserved).



at each junction: $3\,\mathrm{A} = 2\,\mathrm{A} + 1\,\mathrm{A}$

Worked example. If 4.0 A enters a junction and one branch carries 3.0 A, the other branch must carry $4.0 - 3.0 = 1.0$ A.

■ 3 The loop rule

Kirchhoff's loop rule 基尔霍夫电压定律 says that, going around any complete loop, the voltage gains (from the battery) and drops (across resistors) add up to **zero** (energy is conserved).

■ 4 Capacitor circuits

An **RC circuit** has a resistor and a capacitor. The capacitor charges up (or discharges) gradually, over a time set by $\tau = RC$. Right at the start it acts like a plain wire; once fully charged it blocks the current.

Watch out: putting resistors in **parallel** makes the total resistance **smaller** than the smallest one – because you have opened extra paths for the current. Series makes it larger.

Practice

Try these in order. The methods are all above.

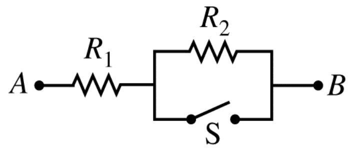
2.1 Find the equivalent resistance of a 3.0 Ω and a 5.0 Ω resistor in **series**. [2]

2.2 Find the equivalent resistance of a 6.0 Ω and a 3.0 Ω resistor in **parallel**. [3]

2.3 A current of 5.0 A enters a junction. One branch carries 2.0 A. Find the current in the other branch. [2]

2.4 State the two conservation ideas behind Kirchhoff's junction rule and loop rule. [2]

2.5 State whether the total resistance of two resistors in parallel is larger or smaller than the smallest resistor, and explain briefly. [2]



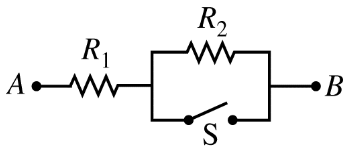
2. (12 points, suggested time 25 minutes)

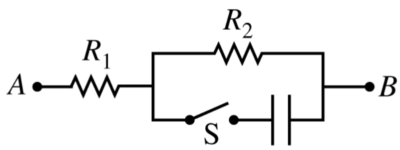
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram

Describe the Experiment





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

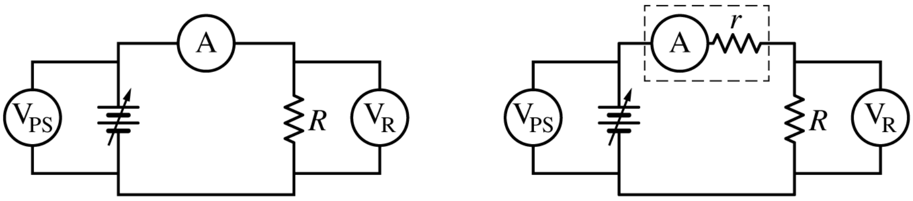
i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.



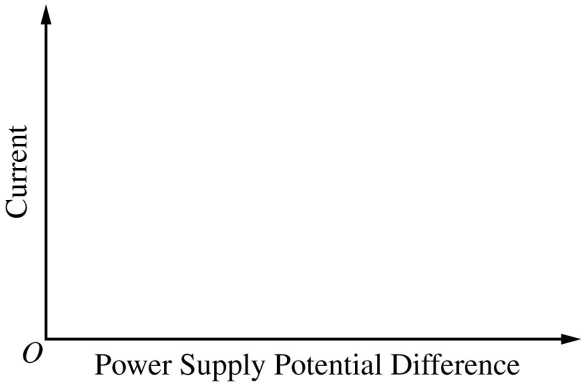
Circuit 1 Circuit 2

2. (12 points, suggested time 25 minutes)

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.



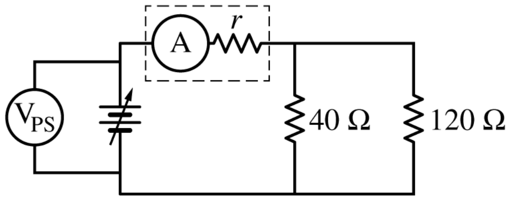
(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

Circuit 1 Circuit 2

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

ii. Calculate the current in each of the resistors that are in parallel.

4. (10 points, suggested time 20 minutes)

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

(a)

i. Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.

ii. Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.

(b) The switch is opened, the capacitor is discharged, and a second, identical capacitor is added to the circuit in series with the other components. The switch is then closed again.

i. A long time after the switch is closed, the energy stored in the single capacitor in the original circuit is U_1 , and the total energy stored in the two capacitors in the new circuit is U_2 . Calculate the ratio U_1/U_2 .

ii. The two capacitors in series are to be replaced with a single capacitor that will have the same energy U_2 . Indicate a plate area and a distance between the plates for the new capacitor, compared with one of the original capacitors, that will accomplish this. Support your reasoning using appropriate physics principles and/or mathematical models.

The students are then asked to design two circuits each containing a switch, a battery with a small internal resistance, a lightbulb, and a capacitor. In arrangement 1, the bulb should gradually light up after the switch is closed, becoming brightest after the switch has been closed a long time. In arrangement 2, the bulb should be brightest when the switch is first closed, getting dimmer with time, and going out completely when the switch has been closed for a long time.

(c) Using standard symbols, draw two circuit diagrams, one showing a possible circuit for arrangement 1 and the other showing a possible circuit for arrangement 2. Justify your circuit diagrams with a paragraph-length explanation referring to the properties of lightbulbs and capacitors in circuits and the conservation of energy and/or the conservation of charge.

STOP

END OF EXAM

12 Magnetic fields and forces – Part 1

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
magnetic field	磁场			
magnetic force	磁力			

Recall

You have played with magnets before:

- A magnet has a north and a south pole; like poles repel, opposite poles attract.
- Magnets pull on iron and steel.
- A coil of wire carrying a current becomes a magnet – an electromagnet.

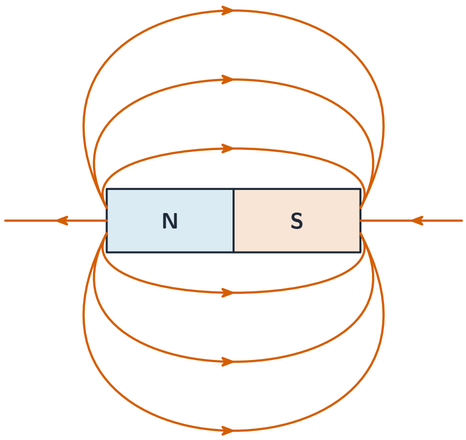
This sheet adds the forces that magnetic fields make. Each idea has a worked example.

New ideas

■ 1 Magnetic fields

A **magnetic field** 磁场 B surrounds every magnet. Field lines run from the **north** pole to the **south** pole outside the magnet, and closer lines mean a stronger field. Poles always come in pairs – cut a magnet in half and you get two smaller magnets, never a single pole.

field lines run from **N** to **S** outside the magnet



■ 2 Force on a moving charge

A charge moving across a magnetic field feels a **magnetic force 磁力**:

$$F = qvB\sin\theta,$$

where θ is the angle between the velocity and the field. The force is at right angles to the motion, so it bends the charge into a **circle** without changing its speed.

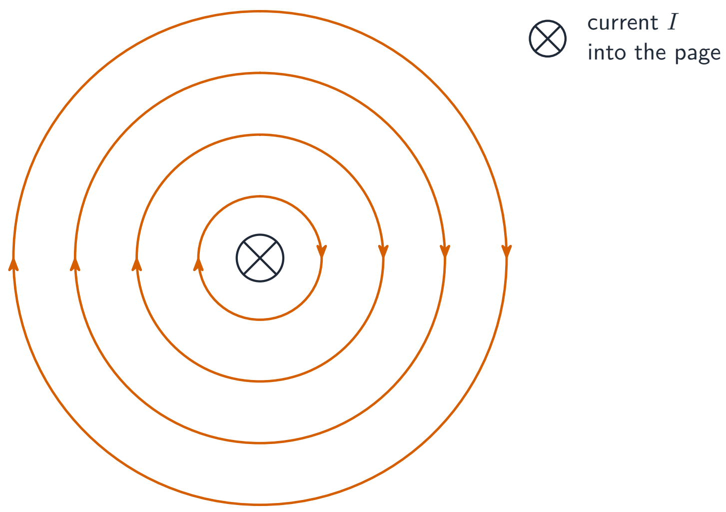
Worked example. A charge of 1.6×10^{-19} C moving at 2.0×10^{5} m/s across a 0.50 T field feels $F = qvB = 1.6 \times 10^{-19} \times 2.0 \times 10^{5} \times 0.50 = 1.6 \times 10^{-14}$ N.

■ 3 Force on a current-carrying wire

A current is moving charge, so a magnetic field pushes on a **current-carrying wire**:

$$F = BIL.$$

This push is what turns the coil in an electric motor.



circular field lines (right-hand grip rule)

Worked example. A 0.30 m wire carrying 4.0 A across a 0.20 T field feels $F = BIL = 0.20 \times 4.0 \times 0.30 = 0.24$ N.

Watch out: a charge that is **not moving**, or one moving **along** the field lines, feels **no** magnetic force. The charge must move **across** the field to feel a push.

Practice

Try these in order. The methods are all above.

2.1 State what happens when you cut a bar magnet in half. [1]

2.2 A charge of 2.0×10^{-19} C moves at 1.0×10^{5} m/s across a 0.40 T field. Find the magnetic force on it. [3]

2.3 A 0.50 m wire carries 3.0 A at right angles to a 0.10 T field. Find the force on it. [2]

2.4 State the direction of the magnetic force on a moving charge, relative to its velocity. [1]

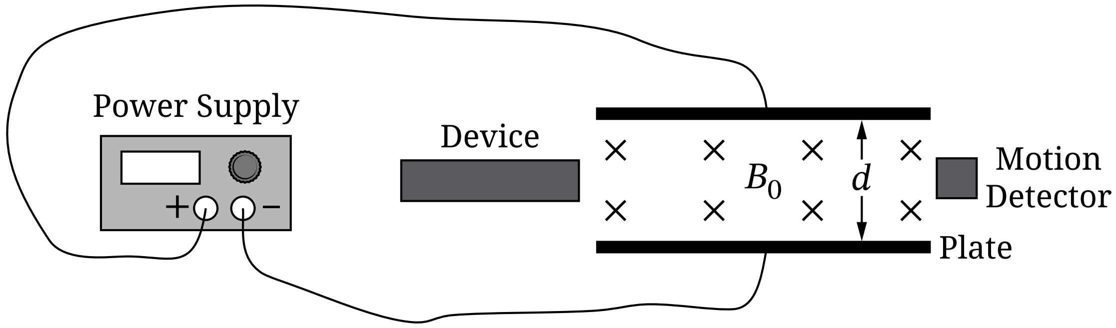
2.5 Explain why a charge moving straight along a magnetic field line feels no magnetic force. [2]

Question 3

The following information applies to parts A and B.

3. In Experiment 1, scientists want to collect data that can be graphed to determine the magnitude B_0 of an external, uniform magnetic field. The field is directed into Figure 1 in the region between identical, parallel, conducting plates that are connected to a power supply of variable emf ε. The plates are a known distance d apart, where d is much smaller than the dimensions of the plates.

Figure 1



Note: Figure not drawn to scale.

In each trial, a device emits small, charged spheres with speed v through the region between the plates. ε is varied until the spheres move undeflected toward a motion detector. The scientists can vary v between trials. Gravitational effects are negligible.

In addition to the equipment shown in Figure 1, the scientists also have access to a voltmeter. The scientists do not have access to other measuring tools, devices, sensors, or equipment.

Part A

i. **Indicate** quantities that could be measured using the available equipment that would allow the scientists to determine B_0 by using a linear graph.

ii. Briefly **describe** a method to reduce experimental uncertainty for the measured quantities indicated in part A (i).

Part B

i. **Indicate** what quantities the scientists could graph on the horizontal and vertical axes to create a linear graph that can be used to determine B_0. Clearly indicate which quantity corresponds to each axis.

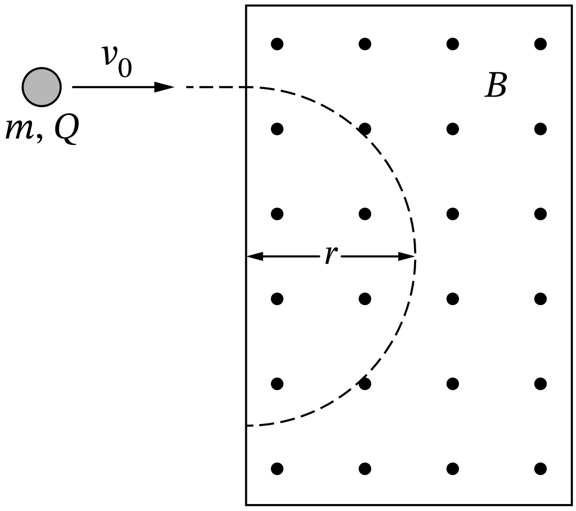
ii. Briefly **describe** the relationship between B_0 and one feature of the graph from part B (i). Your answer may include an equation that relates B_0 and the indicated feature of the graph.

The following information applies to parts C and D.

In Experiment 2, scientists want to use a graph to determine the mass m of identical, charged particles that are emitted from a device. Each particle has charge $Q = +6.4 \times 10^{-19}$ C.

In each trial, a particle is emitted with speed $v_0 = 3.0 \times 10^6$ m/s toward a region of external, uniform magnetic field of variable magnitude B. The radius r of the path along which the particle moves while in the field, shown in Figure 2, is recorded.

Figure 2



In subsequent trials, B is increased and the resulting r is recorded. Gravitational effects are negligible. Collected data are provided in Table 1.

Table 1

B (T)	r (m)
0.04	1.8
0.06	1.2
0.14	0.5
0.16	0.4
0.20	0.3

Part C

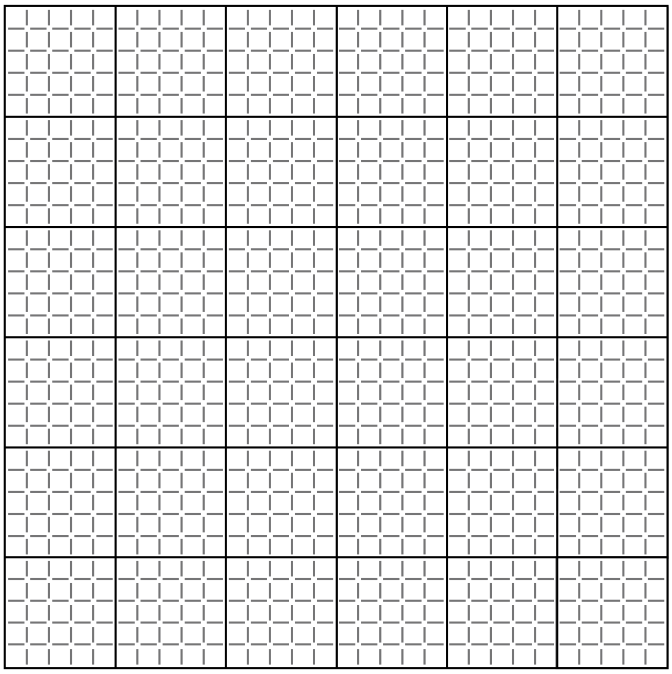
i. **Label** the axes of the grid provided with measured or calculated quantities. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine m.

ii. On the grid, create a graph of the quantities indicated in part C (i).

- **Label** the vertical and horizontal axes with numerical scales.
- **Plot** the corresponding data points on the grid.
- Table 2 is provided in your booklet for scratch work, but the table will not be scored.

Quantity (units, if appropriate)

__________ __________



Quantity (units, if appropriate)

__________ __________

iii. **Draw** a best-fit line for the data graphed in part C (ii).

Part D

Calculate *m* from the best-fit line drawn on the grid.

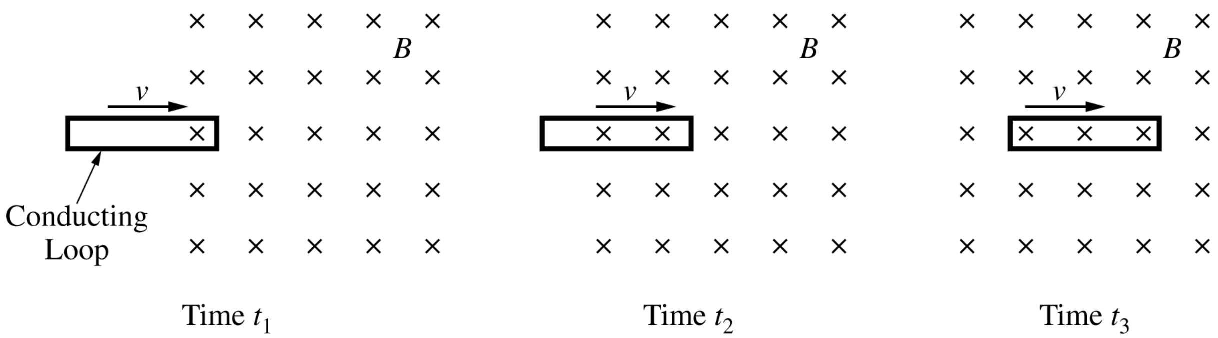
PHYSICS 2

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.

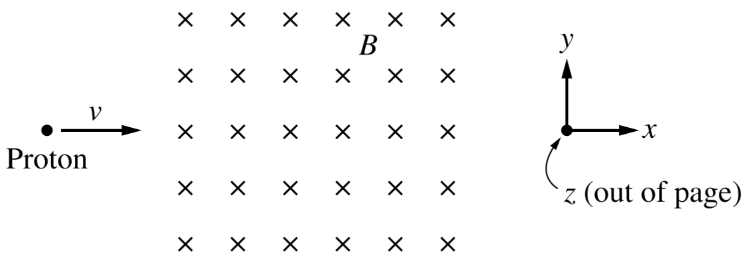


1. (10 points, suggested time 20 minutes)

   The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

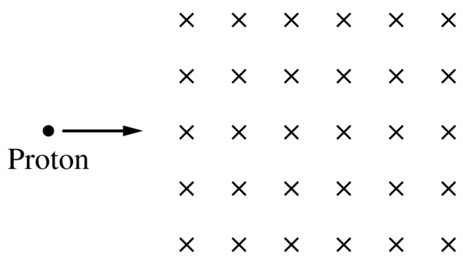
   (a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

12 Electromagnetic induction – Part 2

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
electromagnetic induction	电磁感应			
magnetic flux	磁通量			
Faraday's law	法拉第定律			
Lenz's law	楞次定律			

Recall

In Part A you saw that a current makes a magnetic field. The reverse is just as important:

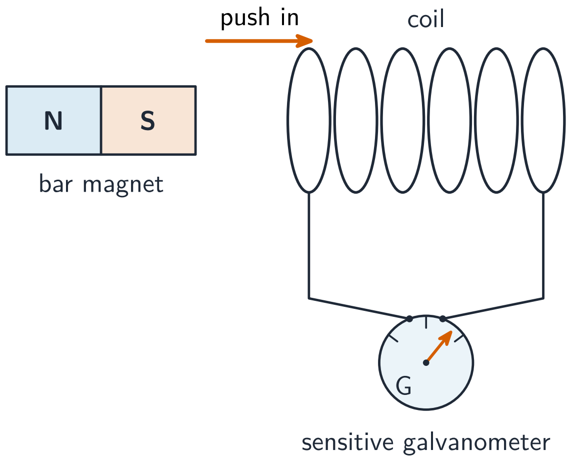
- Move a magnet near a coil of wire and a current appears – with no battery at all.
- This is how every generator and power station makes electricity.

Each idea has a worked example before the Practice.

New ideas

■ 1 Electromagnetic induction

A **changing** magnetic field through a coil drives a current – **electromagnetic induction** 电磁感应. Move a magnet into a coil, or out of it, and a current flows while the magnet is moving.



■ 2 Magnetic flux

The **magnetic flux** 磁通量 $\Phi = BA$ measures how much field passes through a loop of area A. The flux changes if the field strength, the area, or the loop's angle changes.

■ 3 Faraday's law

Faraday's law 法拉第定律 says the induced voltage equals how fast the flux changes:

$$\varepsilon = \frac{\Delta\Phi}{\Delta t}.$$

A coil of N turns gives N times as much.

Worked example. If the flux through a single loop drops from 0.020 Wb to 0.008 Wb in 0.030 s: $\varepsilon = \dfrac{\Delta\Phi}{\Delta t} = \dfrac{0.020 - 0.008}{0.030} = 0.40$ V.

■ 4 Lenz's law

Lenz's law 楞次定律 says the induced current flows in the direction that **opposes** the change that caused it. This is really energy conservation – you must do work to push the magnet, and that work becomes the electrical energy.

Watch out: it is the **change** in flux that induces a current, not the flux itself. A magnet sitting still inside a coil induces **nothing** – the magnet has to be moving.

Practice

Try these in order. The methods are all above.

2.1 State what must happen for a coil to have a current induced in it. [1]

2.2 The flux through a single loop rises from 0.010 Wb to 0.030 Wb in 0.040 s. Find the induced voltage. [3]

2.3 A coil has 50 turns. If one turn would give 0.40 V, what voltage does the whole coil give? [2]

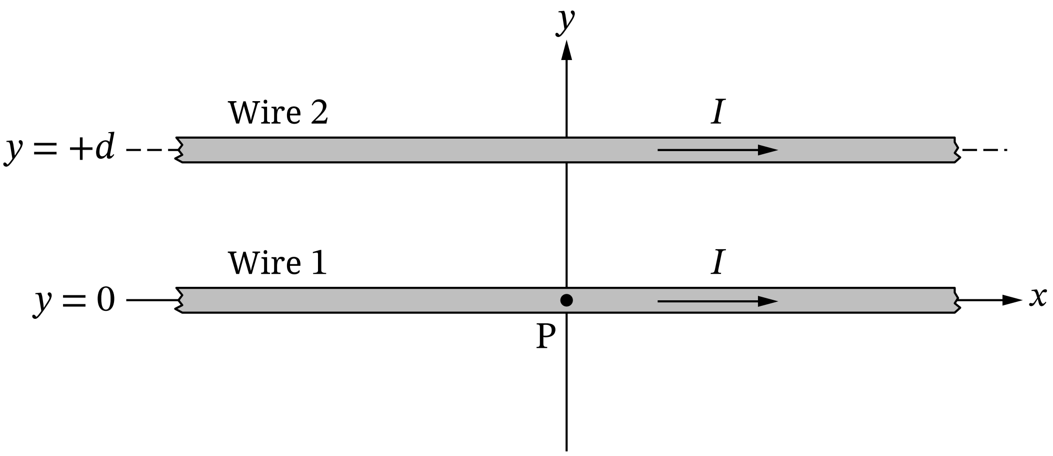
2.4 State what Lenz's law tells you about the direction of an induced current. [1]

2.5 A student holds a magnet still inside a coil and expects a current. Explain why none flows. [2]

Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the *xy*-plane.

Figure 1



Note: Figure not drawn to scale.

A.

i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols

✕ Into the page ● Out of the page

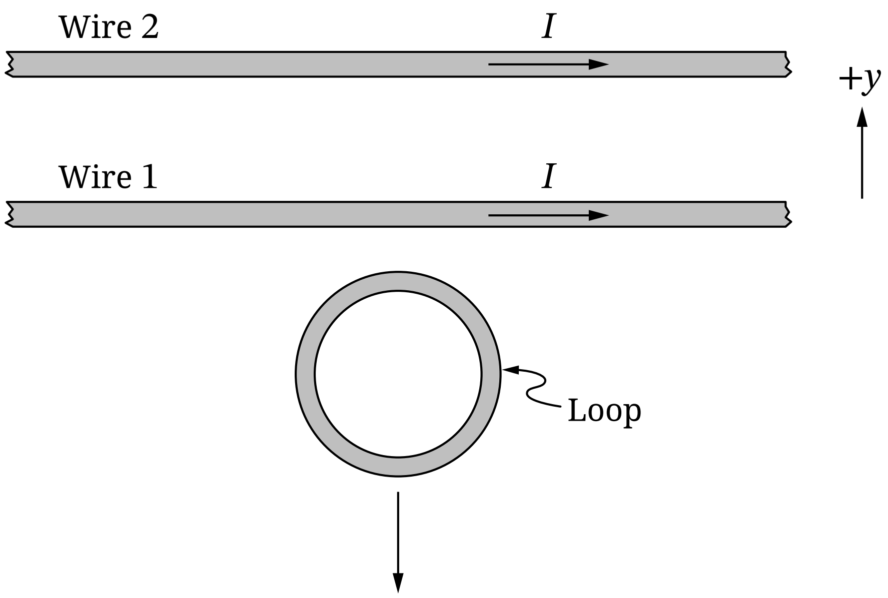
Magnetic Field from Wire 2 at Point P	Magnetic Force on Wire 1 by Wire 2
Figure 2	Figure 3

ii. Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the xy-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the xy-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

______ Clockwise

______ Counterclockwise

______ There is no induced current in the loop.

Justify your answer.

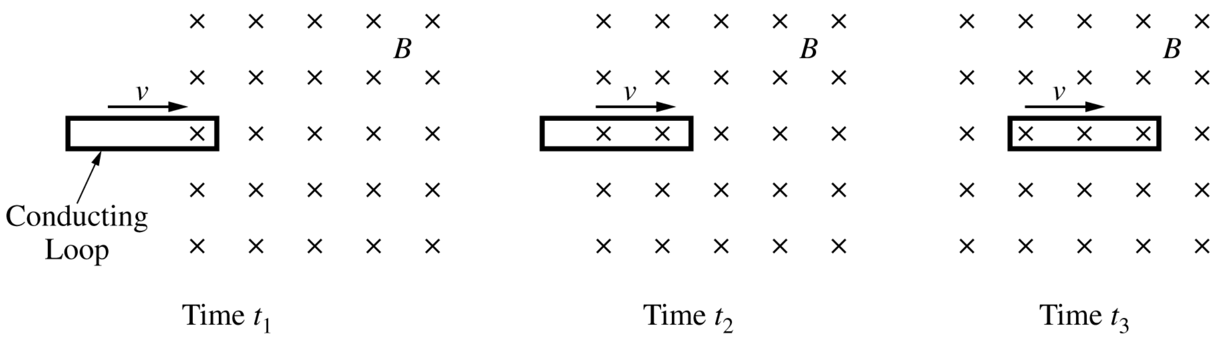
PHYSICS 2

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.

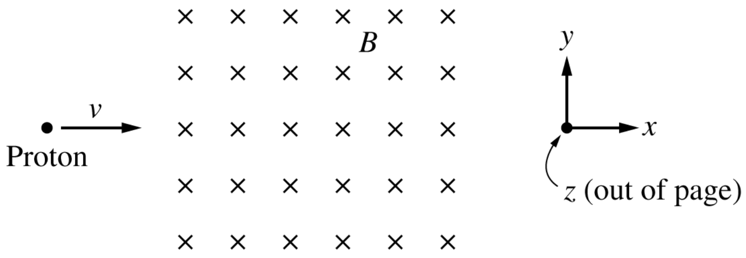


1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

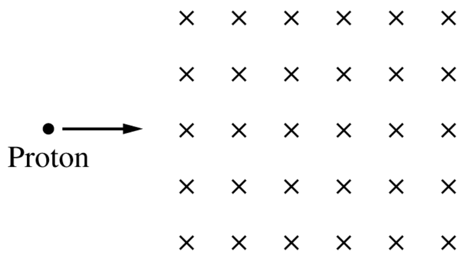
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5\ \text{m/s}$. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

13 Reflection and refraction – Part 1

Name: ________ Class: ________ Date: ________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Geometric optics	几何光学			
law of reflection	反射定律			
angle of incidence	入射角			
angle of reflection	反射角			
refraction	折射			
index of refraction	折射率			
Snell's law	斯涅尔定律			
total internal reflection	全反射			

Recall

You have watched light behave in these ways:

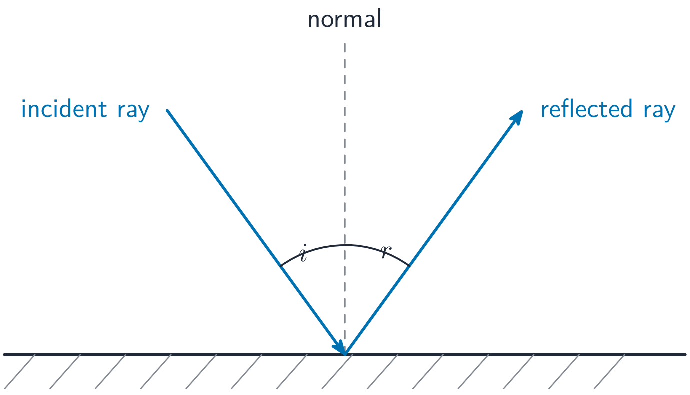
- A mirror bounces light back – you see your reflection.
- A straw in a glass of water looks bent where it enters the water.
- Fibre-optic cables carry light for long distances.

This sheet gives these effects exact laws. Each idea has a worked example.

New ideas

■ 1 Reflection

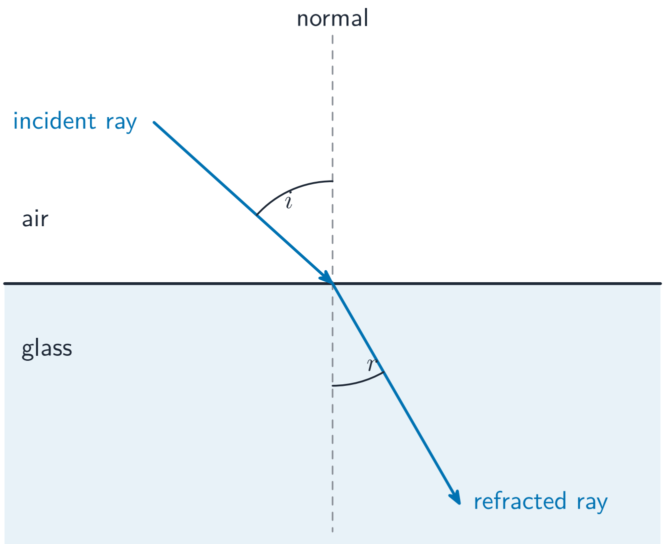
Geometric optics 几何光学 treats light as straight rays. The **law of reflection** 反射定律 says the **angle of incidence** 入射角 equals the **angle of reflection** 反射角, both measured from the **normal** (the line at right angles to the surface).



plane mirror $(i = r)$

■ 2 Refraction

When light passes from one material into another its speed changes, so it bends – **refraction** 折射. Each material has an **index of refraction** 折射率 $n = \dfrac{c}{v}$ (how much it slows light). Light entering a denser material (larger n) bends **toward** the normal.



bends towards the normal $(i > r)$

■ **3 Snell's law**

The bending follows **Snell's law** 斯涅尔定律:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2.$$

Worked example. A ray in air ($n_1 = 1.00$) enters water ($n_2 = 1.33$) at 40°: $\sin\theta_2 = \frac{1.00}{1.33}\sin 40° = 0.483$, so $\theta_2 = 29°$ – it bends toward the normal, as expected going into the denser medium.

■ **4 Total internal reflection**

When light tries to leave a dense material at a steep enough angle, it reflects **entirely** back inside – **total internal reflection** 全反射. This is how optical fibres trap light and carry it for kilometres.

Watch out: all these angles are measured from the **normal**, not from the surface. Measuring from the surface is the most common error in optics.

Practice

Try these in order. The methods are all above.

2.1 A ray hits a mirror at 30° to the normal. State the angle of reflection. [1]

2.2 State what happens to the direction of light entering a denser material (bends toward or away from the normal). [1]

2.3 A ray in air ($n_1 = 1.00$) enters glass ($n_2 = 1.50$) at 30° to the normal. Use Snell's law to find the angle in the glass. [3]

2.4 Glass has an index of refraction of 1.5. Find the speed of light in the glass ($c =$

3.0×10^8 m/s). [2]

2.5 State what total internal reflection is used for, and why it works. [2]

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.

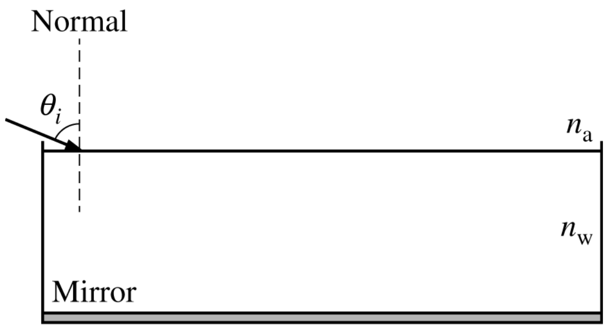
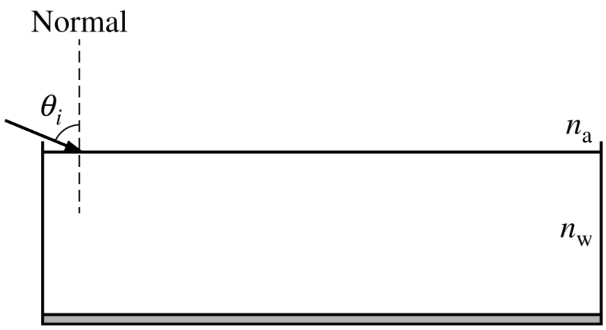


Figure 1

1. (10 points, suggested time 20 minutes)

A rectangular tank with a mirrored bottom is filled with water (index of refraction n_w). A beam of light passes from air (index of refraction n_a) into the water at angle θ_i from the normal, as shown in Figure 1. Index of refraction n_w is greater than index of refraction n_a.

(a) On the following diagram, sketch the entire path of the beam as the beam enters, travels through, and then exits the water.



GO ON TO THE NEXT PAGE.

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

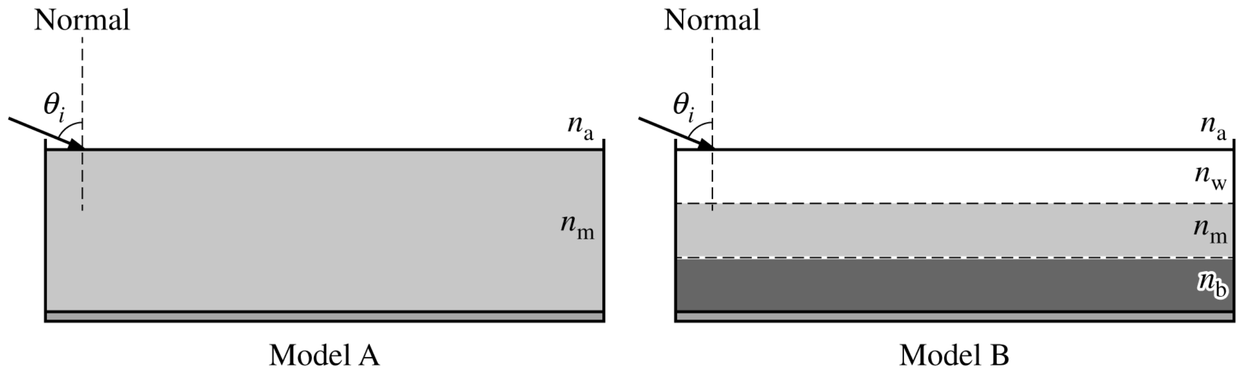


Figure 2

Sugar is then added to the water, resulting in a mixture that has a different index of refraction than water. A student considers two models, Model A and Model B, for how the sugar mixes with water. The models are shown in Figure 2.

Model A: The sugar is uniformly mixed throughout the water, resulting in a mixture with index of refraction n_m such that $n_m > n_w$.

Model B: Layers are formed of varying concentrations of sugar in the water. There are three distinct layers of equal volume. The top layer is only water (index of refraction n_w). The middle layer has the same concentration of sugar as the mixture in Model A (index of refraction n_m). The bottom layer has the highest concentration of sugar (index of refraction n_b).

(b) Consider Model A. Briefly describe how the observed wavelength of light changes, if at all, as the beam travels from air into the mixture.

GO ON TO THE NEXT PAGE.

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

(c) Relevant angles between the beam and the normal for the various layers present in models A and B are defined in the following table.

Model A		Model B	
θ_i	Incident angle of the beam in air	θ_i	Incident angle of the beam in air
θ_1	Angle the beam makes with the normal in the mixture in Model A	θ_2	Angle the beam makes with the normal in the top layer in Model B
		θ_3	Angle the beam makes with the normal in the middle layer in Model B
		θ_4	Angle the beam makes with the normal in the bottom layer in Model B

i. Determine an expression for θ_4 in terms of θ_i, n_a, and n_b.

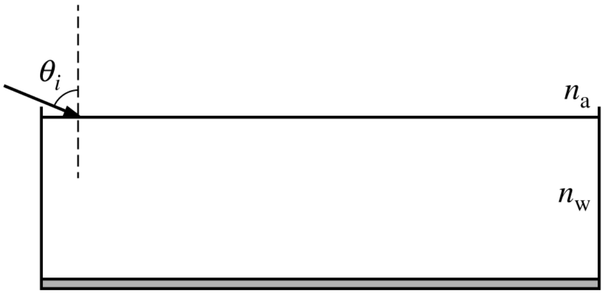
ii. Rank the angles from greatest to least, with 1 being greatest. If two angles are the same value, give them the same ranking.

____ θ_1 ____ θ_2 ____ θ_3 ____ θ_4

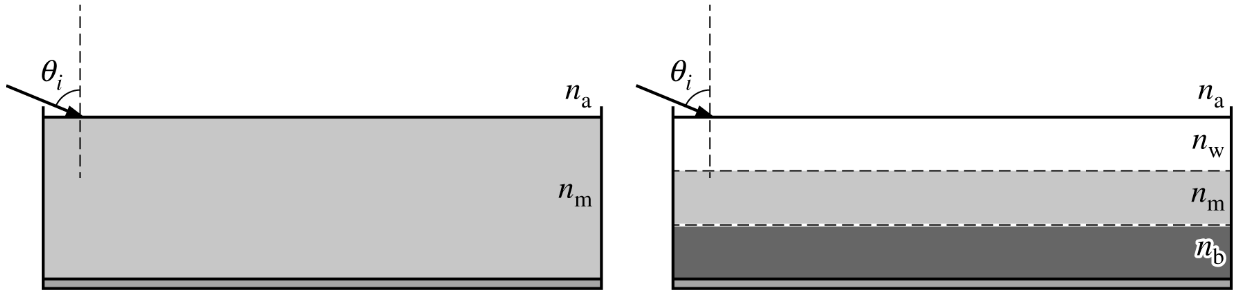
Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

GO ON TO THE NEXT PAGE.

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



Original Tank



Model A

Model B

For the original tank filled with water, the beam is observed to exit the surface of the water a horizontal distance d_w from the entry point. For models A and B, the horizontal distances are d_A and d_B, respectively.

(d) Determine whether d_A and d_B are each greater than, less than, or equal to d_w. It is NOT necessary to compare d_A to d_B. Briefly justify your answer.

GO ON TO THE NEXT PAGE.

13 Images from mirrors and lenses – Part 2

Name: ____________ Class: ________ Date: __________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
converging	会聚			
diverging	发散			
real image	实像			
virtual image	虚像			

Recall

In Part A you saw light reflect and refract. Now those effects form **images**:

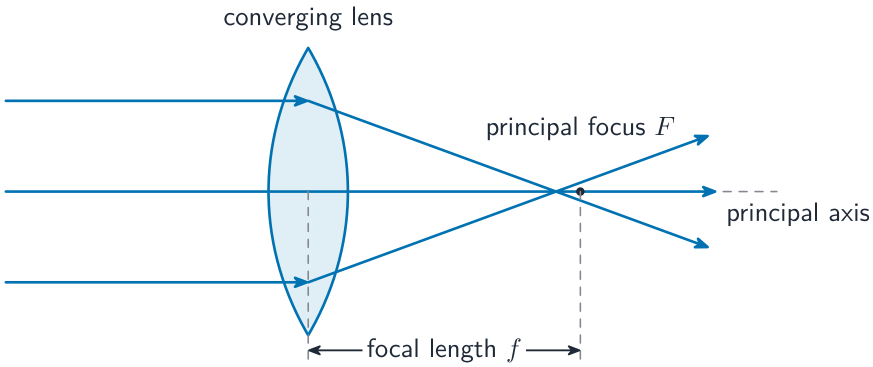
- A magnifying glass makes small print look bigger.
- A camera lens makes a small picture on its sensor.
- A curved mirror can focus light to a point.

Each idea has a worked example before the Practice.

New ideas

■ 1 A converging lens

A **converging** 会聚 (convex) lens bends parallel rays to meet at its **focal point**, a distance f away.



A **diverging** 发散 (concave) lens spreads rays out instead.

2 The thin-lens equation

For an object a distance d_o from a lens, the image forms at d_i where

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}.$$

Worked example. An object 30 cm from a converging lens with $f = 10$ cm: $\frac{1}{d_i} = \frac{1}{10} - \frac{1}{30} = \frac{2}{30}$, so $d_i = 15$ cm.

3 Magnification

The **magnification** is

$$m = -\frac{d_i}{d_o},$$

where the size tells you how much bigger, and the sign tells you upright (+) or inverted (−).

Worked example. For the lens above, $m = -\frac{15}{30} = -0.5$ – the image is half-size and inverted (a camera picture).

4 Real and virtual images

- A **real image** 实像 forms where rays actually meet – you can catch it on a screen (a camera, a projector).
- A **virtual image** 虚像 only appears to be there – you see it by looking through the lens (a magnifying glass).

Watch out: a **positive** image distance means a real image (on a screen); a **negative** one means a virtual image (seen by looking through). Keep the signs straight.

Practice

Try these in order. The methods are all above.

2.1 State what a converging lens does to parallel rays of light. [1]

2.2 An object is 20 cm from a converging lens of focal length $f = 5.0$ cm. Find the image distance. [3]

2.3 For the lens in 2.2, find the magnification. [2]

2.4 State whether the image in 2.2 is upright or inverted, and how you can tell. [1]

2.5 Give one everyday device that uses a real image and one that uses a virtual image. [2]

2. (12 points, suggested time 25 minutes)

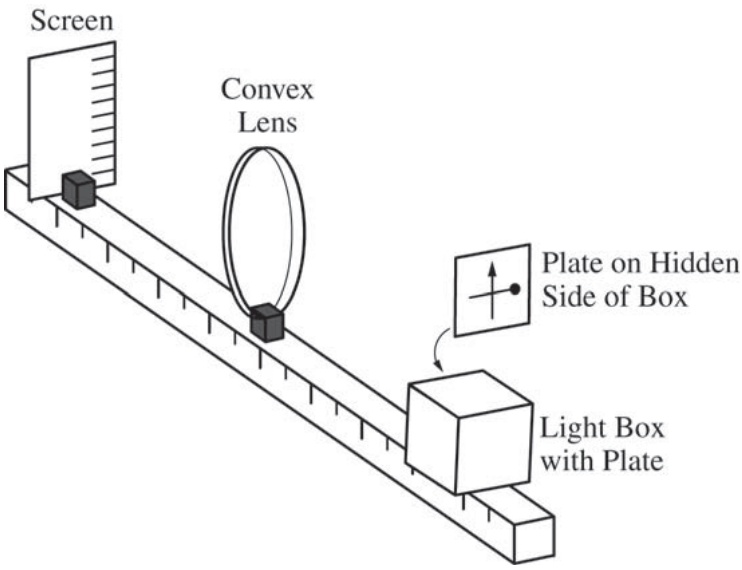
A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp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

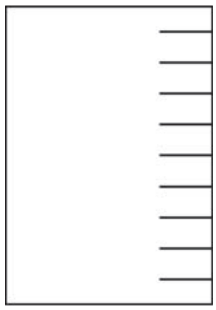


3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.



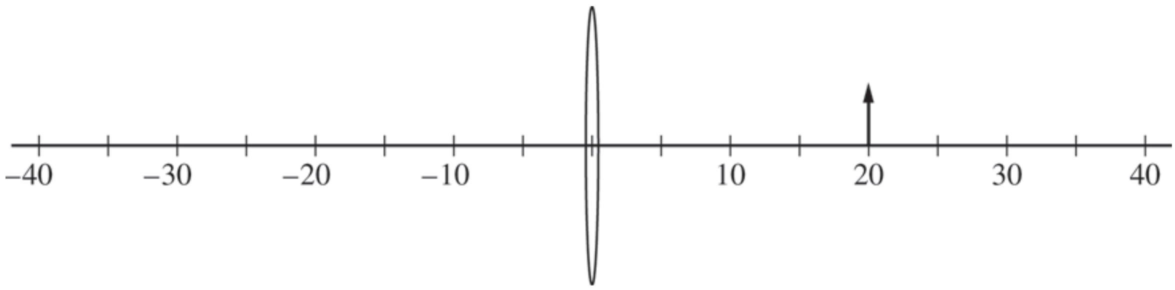
(b)

i. Calculate the focal length of the lens.

ii. Calculate the magnitude of the magnification of the image.

(c)

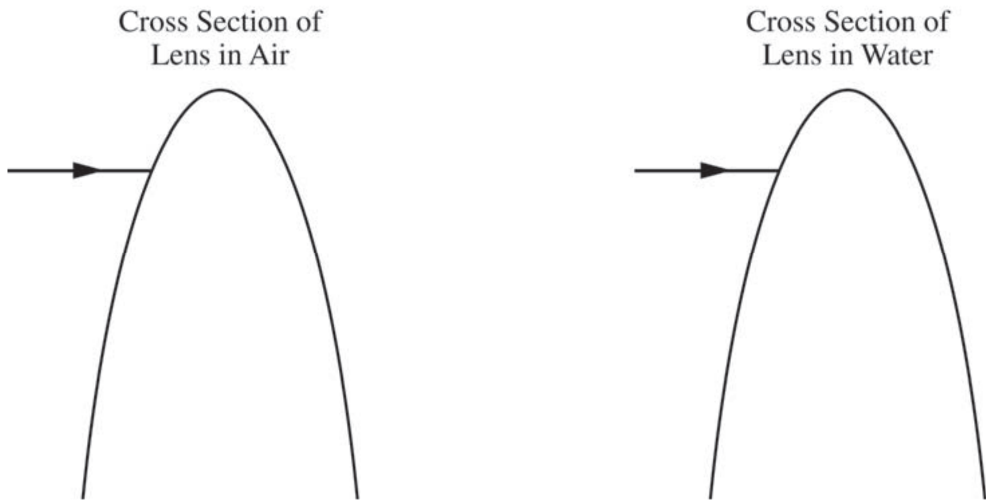
i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

(d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.



ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

14 Waves, sound, and the wave equation – Part 1

Name: ____________ Class: ________ Date: __________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
wave	波			
Transverse	横波			
Longitudinal	纵波			
wavelength	波长			
frequency	频率			
amplitude	振幅			
wave speed	波速			
Electromagnetic waves	电磁波			
Doppler effect	多普勒效应			

Recall

Waves are all around you:

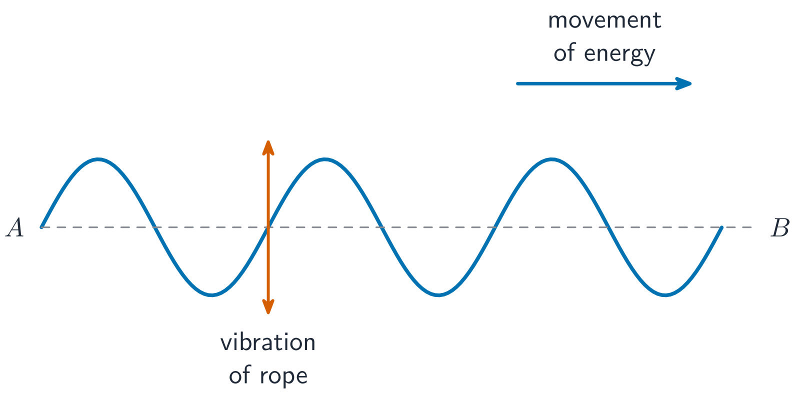
- Ripples spread across a pond; sound travels through the air; light reaches you from a lamp.
- A wave carries **energy** from place to place, but the water or air itself stays put.
- You have used speed = frequency × wavelength before.

This sheet lines up the wave ideas the AP course builds on. Each idea has a worked example.

New ideas

■ 1 What a wave is

A **wave** 波 carries energy without carrying the material along. There are two kinds:



- **Transverse** 横波: the material moves at right angles to the wave (a rope wave, light).
- **Longitudinal** 纵波: the material moves back and forth along the wave (sound).

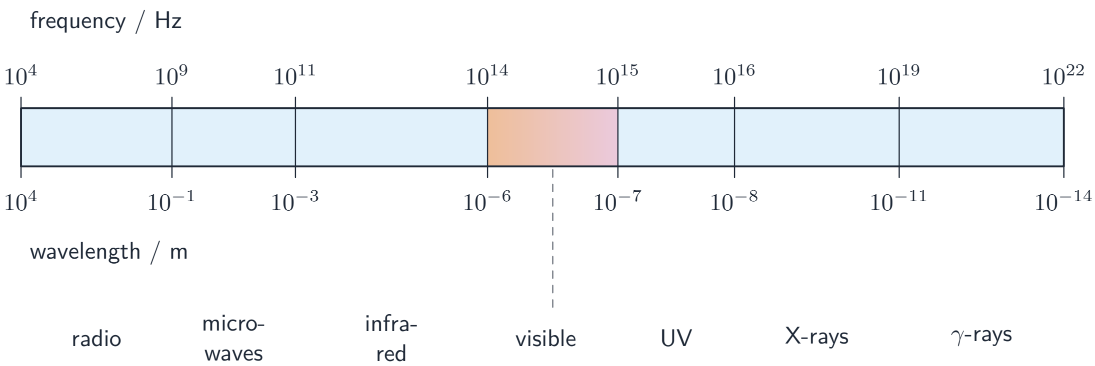
■ 2 Describing a wave

- **wavelength** 波长 λ – the distance between repeats,
- **frequency** 频率 f – cycles per second,
- **amplitude** 振幅 A – the largest displacement (linked to energy),
- **wave speed** 波速: $v = f\lambda$, set by the material the wave travels in.

Worked example. A note of frequency 340 Hz travels through air at 340 m/s, so its wavelength is $\lambda = \dfrac{v}{f} = \dfrac{340}{340} = 1.0$ m.

■ 3 Electromagnetic waves

Electromagnetic waves 电磁波 (radio, light, X-rays) are made of oscillating electric and magnetic fields. They all travel through empty space at the speed of light $c = 3.0 \times 10^8$ m/s and need no material.



■ **4 The Doppler effect**

The **Doppler effect** 多普勒效应 is the change in the frequency you hear when a source moves toward or away from you: approaching sounds higher-pitched, moving away sounds lower. It is why a passing siren drops in pitch.

Watch out: when a wave moves into a new material, its **frequency stays the same** (set by the source) but its **speed and wavelength change**. Do not assume the wavelength is fixed.

Practice

Try these in order. The methods are all above.

2.1 State the difference between a transverse and a longitudinal wave, with one example of each. [2]

2.2 A wave has frequency 50 Hz and wavelength 0.40 m. Find its speed. [2]

2.3 A radio wave travels at 3.0×10^8 m/s with frequency 1.0×10^8 Hz. Find its wavelength. [2]

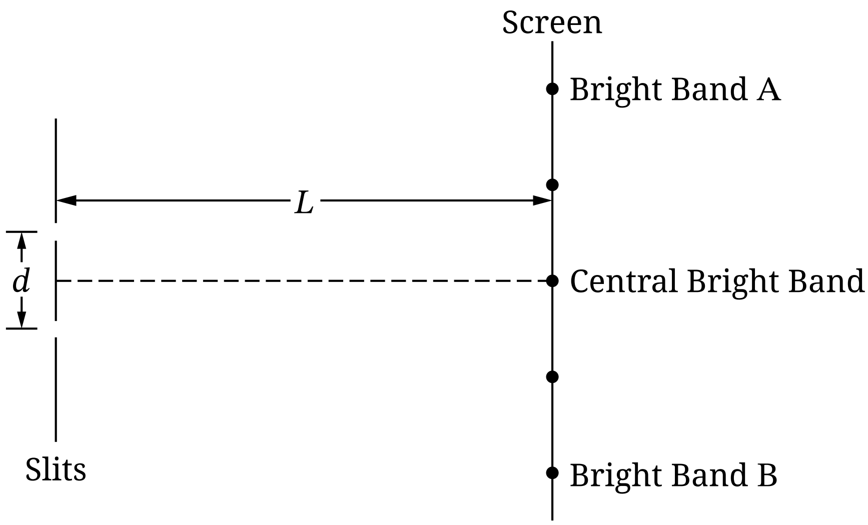
2.4 A siren passes you at speed. Describe how the pitch you hear changes as it approaches and then moves away. [2]

2.5 A sound of frequency 200 Hz passes from air (speed 340 m/s) into water (speed

1500 m/s). State what happens to its frequency and to its wavelength. [2]

Question 4

4. Two narrow slits are a distance d apart. A screen is a distance L from the midpoint of the slits, where $L \gg d$. When a laser emits monochromatic light toward the slits, a pattern of narrow bright and dark bands is observed on the screen. The centers of bright bands A and B are indicated. Three additional bright bands, including the central bright band, are observed on the screen between bands A and B, as shown.



Note: Figure not drawn to scale.

A student claims that the distance between the center of Band A and the center of the central bright band is smaller when using a laser that emits violet light than when using a laser that emits red light.

A. **Indicate** whether the student's claim is correct or incorrect. Without manipulating equations, **justify** your answer by referencing the difference in path length traveled by the light from each slit to the center of Band A.

B. **Derive** an expression for the distance between the centers of bands A and B when light of frequency f is emitted toward the slits. Express your answer in terms of d, L, f, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. **Indicate** whether the expression you derived in part B is or is not consistent with your answer from part A. Briefly **justify** your answer.

STOP

END OF EXAM

14 Interference, standing waves, and diffraction – Part 2

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
Constructive interference	相长干涉			
Destructive interference	相消干涉			
standing wave	驻波			
nodes	波节			
antinodes	波腹			
Diffraction	衍射			

Recall

In Part A you described single waves. Now see what happens when **two** waves meet:

- Two sets of ripples cross and make a criss-cross pattern.
- A guitar string vibrates in a fixed shape and sounds a clear note.
- Waves bend around a corner so you hear sound from another room.

Each idea has a worked example before the Practice.

New ideas

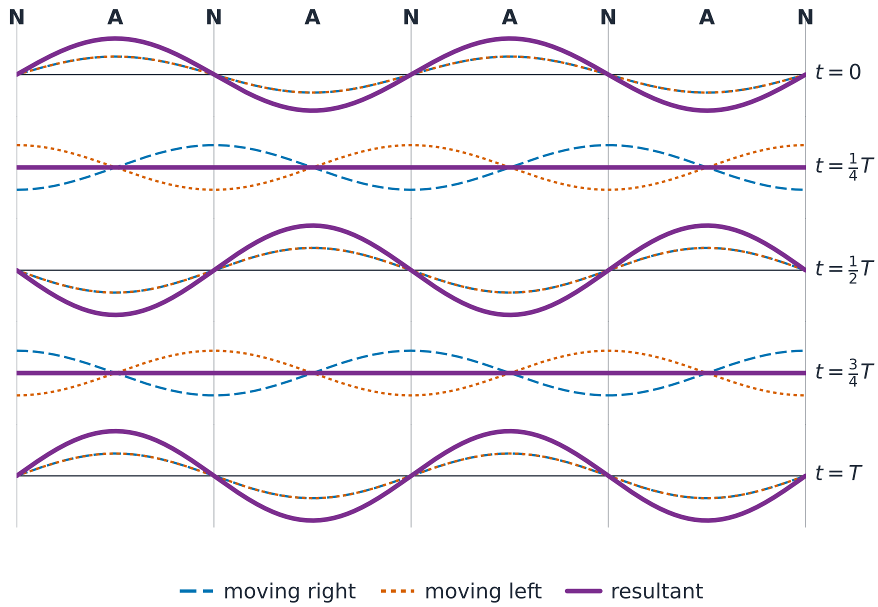
1 Adding waves (superposition)

When two waves overlap they simply **add**:

- **Constructive interference** 相长干涉 – crest meets crest – makes a bigger wave.
- **Destructive interference** 相消干涉 – crest meets trough – cancels out.

2 Standing waves

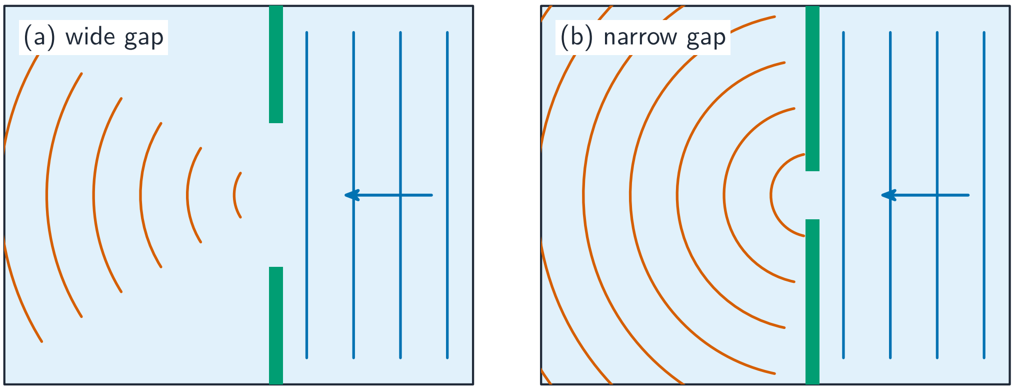
Two waves travelling in opposite directions in a fixed space form a **standing wave** 驻波, with **nodes** 波节 (points that never move) and **antinodes** 波腹 (points that move the most). This is how a guitar string or a pipe makes a note.



Worked example. A string 0.65 m long, fixed at both ends, fits half a wavelength in its simplest note, so $\lambda = 2L = 1.30$ m. If waves travel at 260 m/s, the note is $f = \dfrac{v}{\lambda} = \dfrac{260}{1.30} = 200$ Hz.

3 Diffraction

Diffraction 衍射 is the bending and spreading of waves around edges or through gaps. It is largest when the gap is about the same size as the wavelength.



gap $\gg \lambda$: little spreading

gap $\approx \lambda$: strong spreading

■ 4 The double slit

Light passing through two close slits makes a pattern of bright and dark **fringes**, where the waves interfere. Bright fringes appear where the two paths differ by a whole number of wavelengths.

Watch out: diffraction is only obvious when the gap is close to the wavelength. Sound (long wavelength) bends around a doorway easily; light (tiny wavelength) needs a very narrow slit to spread noticeably.

Practice

Try these in order. The methods are all above.

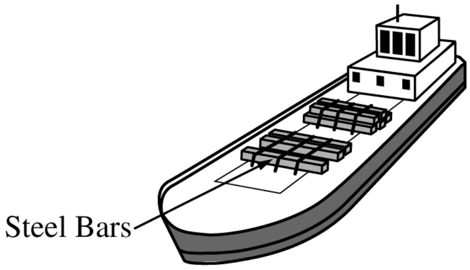
2.1 State what happens when a crest of one wave meets (a) a crest of another, (b) a trough of another. [2]

2.2 On a standing wave, state what a node is and what an antinode is. [2]

2.3 A string 0.50 m long, fixed at both ends, has $\lambda = 2L$ in its simplest note. Waves travel at 300 m/s. Find the frequency of the note. [3]

2.4 Explain why you can hear sound coming from around a corner, but cannot see around it. [2]

2.5 State what you would see on a screen when light passes through two closely spaced slits. [1]



4. (10 points, suggested time 20 minutes)

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) Derive an expression for the maximum number *N* of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

(b) The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.

(c) Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

STOP

END OF EXAM

15 Photons and the atom – Part 1

Name: __________ Class: ________ Date: ________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
quanta	量子			
photons	光子			
Wave–particle duality	波粒二象性			
energy levels	能级			
photoelectric effect	光电效应			
work function	逸出功			

Recall

You have heard some surprising ideas about light and atoms:

- Light comes in tiny packets called photons, not just a smooth wave.
- Atoms give off particular colours – think of the orange glow of a street lamp.
- Shining light on some metals can knock electrons out.

This sheet makes these quantum ideas exact. Each idea has a worked example.

New ideas

■ 1 Photons

At tiny scales, energy comes in packets called **quanta** 量子. Light is carried by **photons** 光子, each with energy set by its frequency:

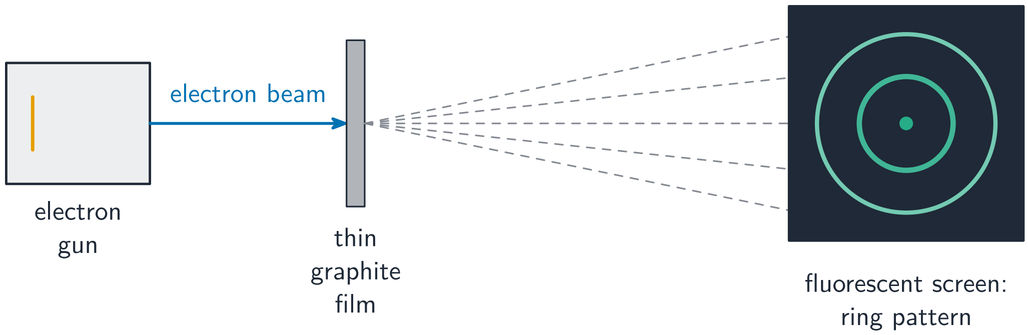
$$E = hf,$$

where $h = 6.63 \times 10^{-34}$ J s is Planck's constant. Higher-frequency light means higher-energy photons.

Worked example. A green-light photon of frequency 5.0×10^{14} Hz carries $E = hf = 6.63 \times 10^{-34} \times 5.0 \times 10^{14} = 3.3 \times 10^{-19}$ J.

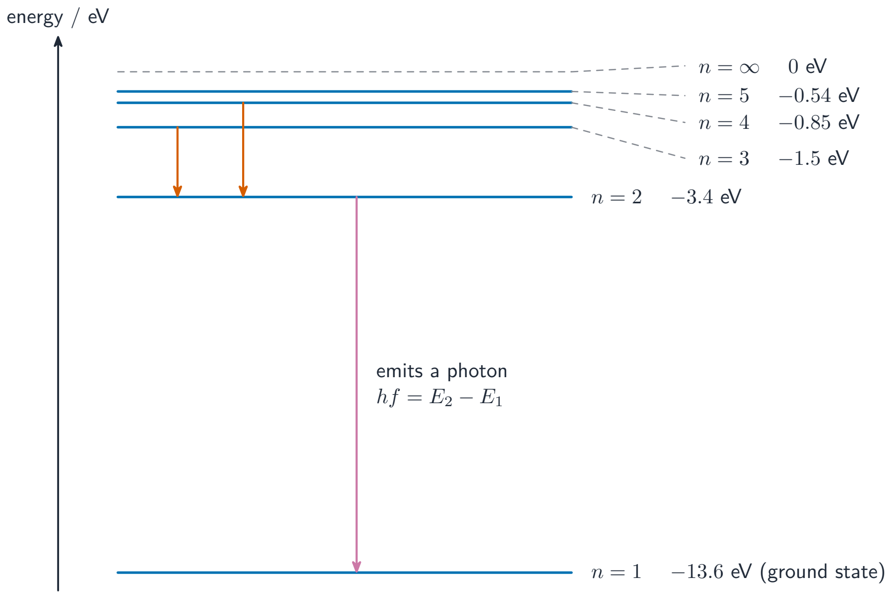
2 Wave–particle duality

Wave–particle duality 波粒二象性 means light (and even matter) shows **both** wave behaviour (interference, diffraction) and particle behaviour (photons, single hits).



3 Energy levels

An atom's electrons can sit only in certain **energy levels** 能级. An electron jumps between levels by absorbing or emitting a photon whose energy exactly matches the gap. Because the gaps are fixed, each element gives off its own set of colours – a fingerprint.



■ **4 The photoelectric effect**

Shining light on a metal can eject electrons – the **photoelectric effect 光电效应** – but only if the photon's frequency is high enough. The escaping electron's energy is

$$K_{\max} = hf - \phi,$$

where ϕ is the **work function 逸出功** (the energy needed to free an electron).

Watch out: below the threshold frequency, **no** electrons come out, no matter how bright the light. Brightness adds more photons, but each one must individually be energetic enough.

Practice

Try these in order. The methods are all above.

2.1 Find the energy of a photon of frequency 4.0×10^{14} Hz ($h = 6.63 \times 10^{-34}$ J s). [2]

2.2 State what "wave–particle duality" means, in one sentence. [1]

2.3 An electron drops between two energy levels, emitting a photon. State what decides the photon's energy. [1]

2.4 Light of frequency 9.0×10^{14} Hz hits a metal with work function $\phi = 4.0 \times 10^{-19}$ J. Find the maximum kinetic energy of an ejected electron. [3]

2.5 A very bright red light shines on a metal but ejects no electrons, while a dim blue light does. Explain why. [2]

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.

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.

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 The nucleus - fission, fusion, and decay – Part 2

Name: ______________ Class: __________ Date: ____________

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
nucleus	原子核			
Fission	裂变			
Fusion	聚变			
radioactive decay	放射性衰变			
alpha	阿尔法衰变			
beta	贝塔衰变			
gamma	伽马衰变			
half-life	半衰期			

Recall

You already know some nuclear physics:

- Atoms have a tiny, dense **nucleus** of protons and neutrons.
- Some atoms are **radioactive** and give off radiation.
- Nuclear power and the Sun both release huge amounts of energy.

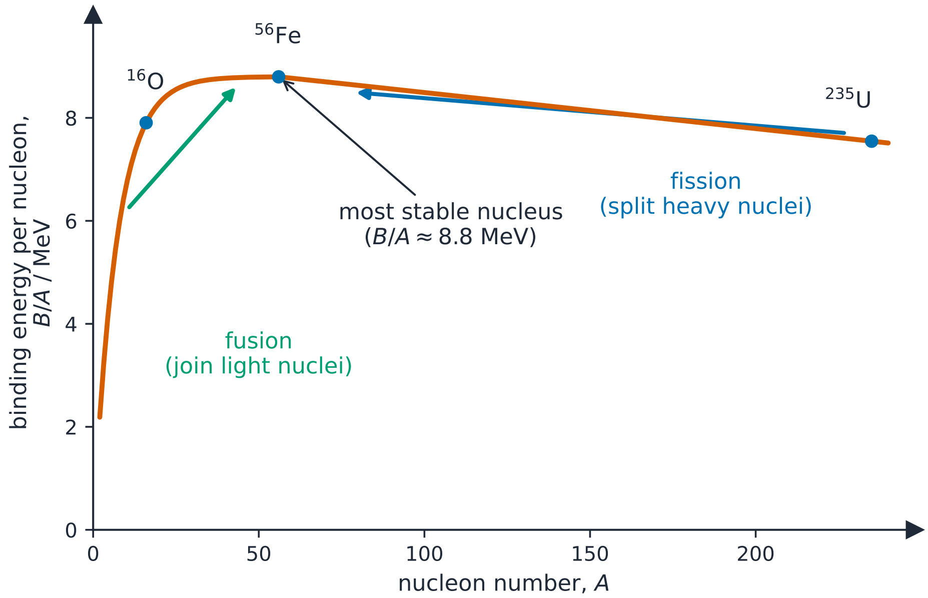
This sheet explains where that energy comes from. Each idea has a worked example.

New ideas

■ 1 Energy from the nucleus

The **nucleus** 原子核 stores enormous energy. Two processes release it:

- **Fission** 裂变 splits a heavy nucleus into lighter pieces (nuclear reactors).
- **Fusion** 聚变 joins light nuclei into a heavier one (the Sun).



■ 2 Mass becomes energy

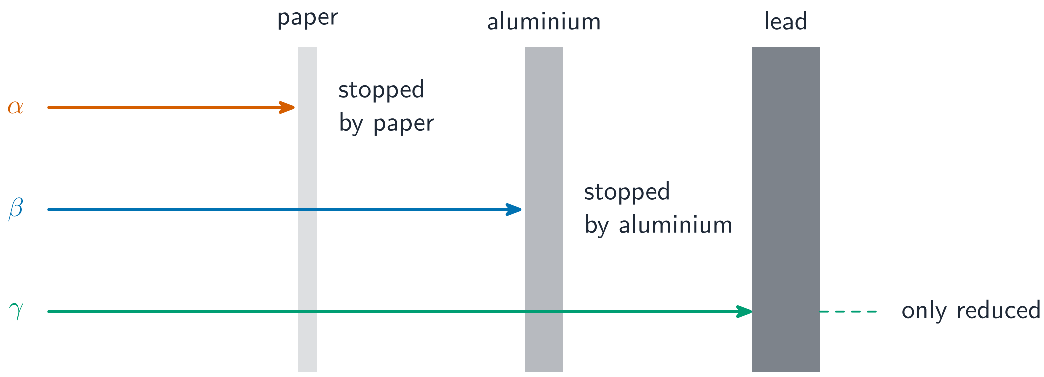
Both release energy because the products have slightly **less mass** than the starting materials, converted by Einstein's equation

$$E = mc^2.$$

Worked example. If a reaction loses 1.0×10^{-3} kg of mass, it releases $E = mc^2 = 1.0 \times 10^{-3} \times (3.0 \times 10^8)^2 = 9.0 \times 10^{13}$ J – a tiny mass, an enormous energy.

■ 3 Radioactive decay

Unstable nuclei undergo **radioactive decay** 放射性衰变, emitting three kinds of radiation:



- **alpha** 阿尔法衰变 – a helium nucleus (stopped by paper),
- **beta** 贝塔衰变 – a fast electron (stopped by aluminium),
- **gamma** 伽马衰变 – a high-energy photon (needs thick lead).

■ 4 Half-life

Decay is random, but a sample halves every **half-life** 半衰期: after each half-life, half of the remaining nuclei have decayed.

Worked example. A sample has a half-life of 8.0 days. After 24 days that is $24/8.0 = 3$ half-lives, so the fraction left is $\left(\frac{1}{2}\right)^3 = \frac{1}{8}$ (about 12.5%).

Watch out: in every decay, the total **mass number** and total **charge** are conserved – use this to balance a decay equation and find the new nucleus.

Practice

Try these in order. The methods are all above.

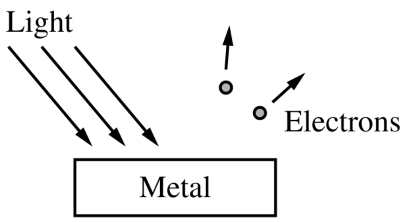
2.1 State the difference between nuclear fission and nuclear fusion. [2]

2.2 A nuclear reaction loses 2.0×10^{-4} kg of mass. Find the energy released ($c = 3.0 \times 10^8$ m/s). [3]

2.3 Name the three types of radioactive decay, in order of increasing penetrating power. [2]

2.4 A sample has a half-life of 5.0 years. What fraction remains after 15 years? [3]

2.5 State the two quantities that are always conserved in a radioactive decay. [1]

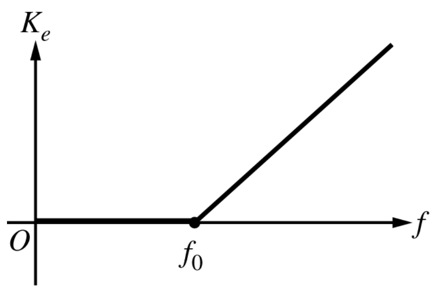


3. (12 points, suggested time 25 minutes)

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.

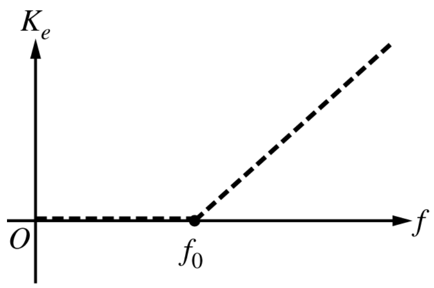
(a)

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 $f \leq f_0$, 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.

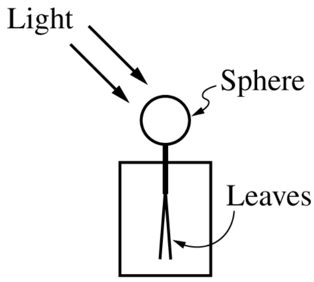


ii. Explain the physical meaning of the horizontal section of the graph between the origin and f_0.

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.

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.

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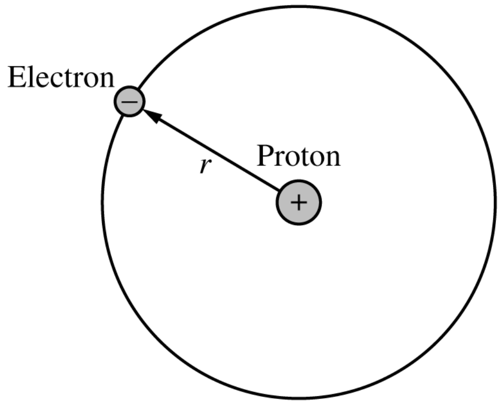
STOP

END OF EXAM

Begin your response to **QUESTION [illegible]** 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.

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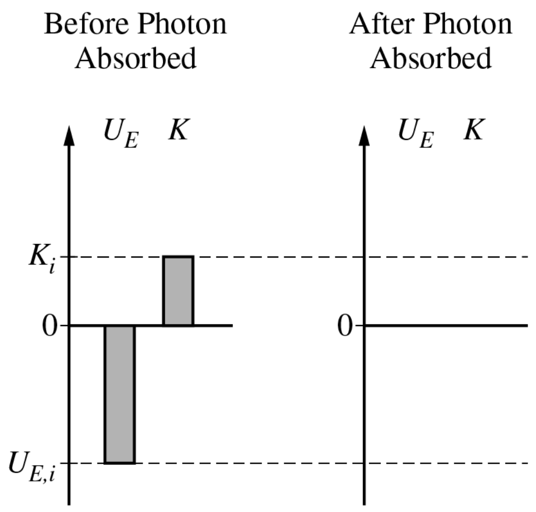
Continue your response to **QUESTION 3** on this page.



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.