HOLIDAY HOMEWORK 假期作业

AP Physics 1

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

1 Describing motion and reading graphs – 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)		
Kinematics	运动学			
scalar	标量			
magnitude	大小			
vector	矢量			
Distance	距离			
Displacement	位移			
Speed	速率			
Velocity	速度			
Acceleration	加速度			
deceleration	减速			
gradient	斜率			

Recall

You met motion long before AP. Bring it with you:

- You measured **distance** with a ruler and **time** with a clock, and found **speed** from speed = distance ÷ time.

- You described a moving car, a falling ball, a running friend – how fast each one goes.
- At AP we look more carefully at **direction** (not just how fast, but which way) and at how motion **changes**.

Nothing on this sheet is harder than what you already know. It just lines up the ideas the AP course starts with.

New ideas

Read these first. Each idea has a short worked example. Once you have read them you can do the Practice below.

■ 1 Distance and displacement

Kinematics 运动学 is the study of how things move. It uses two kinds of quantity.

A **scalar** 标量 has only size (its **magnitude** 大小): distance, speed, time, mass. A **vector** 矢量 has size **and** direction: displacement, velocity, acceleration.

Distance 距离 is the whole path length you travel – it only grows. **Displacement** 位移 is the straight line from start to finish, together with a direction.

Worked example. Walk 3 m east, then 1 m back west. The distance is $3 + 1 = 4$ m, but the displacement is only 2 m east – how far you ended from where you began.

■ 2 Speed and velocity

Speed 速率 tells you how fast, as a scalar. **Velocity** 速度 tells you how fast **and** which way, so it is a vector.

In one dimension, direction is just a **sign**. First choose which way is positive. Then a velocity of -5 m/s means 5 m/s in the negative direction – it does **not** mean "slow."

Worked example. A car covers 100 m in 5 s in the $+x$ direction, so its velocity is $\frac{100}{5} = +20$ m/s. A car going the other way at the same rate has velocity -20 m/s.

■ 3 Acceleration

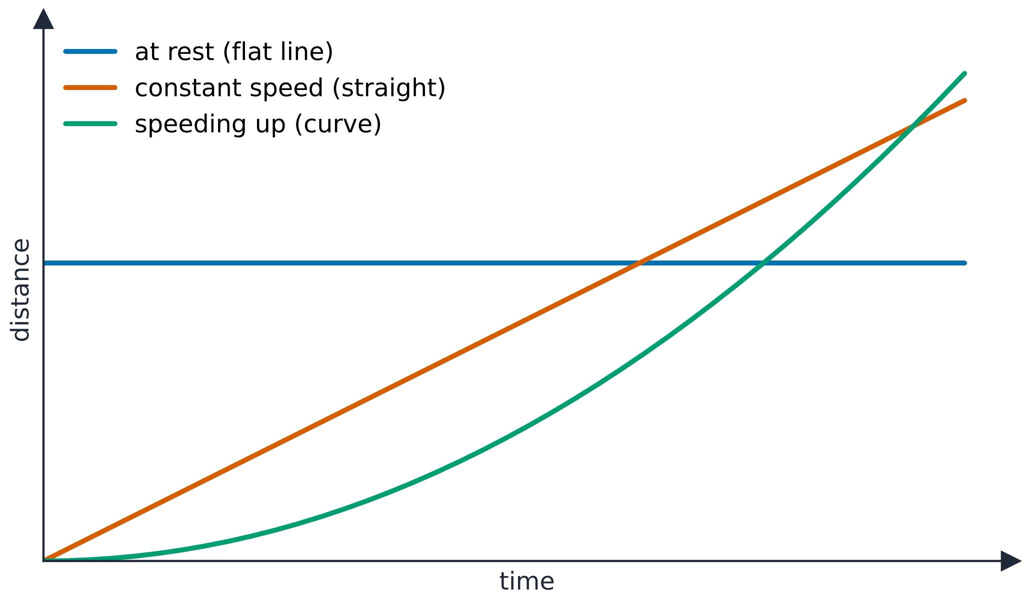
Acceleration 加速度 is how quickly velocity changes: $a = \frac{\Delta v}{\Delta t}$ (change in velocity ÷ time taken). Its unit is m/s^2.

An object speeds up when velocity and acceleration point the **same** way, and slows down (**deceleration** 减速) when they point **opposite** ways.

Worked example. A bike speeds up from 2 m/s to 8 m/s in 3 s: $a = \frac{8-2}{3} = 2$ m/s^2.

■ 4 Position–time graphs

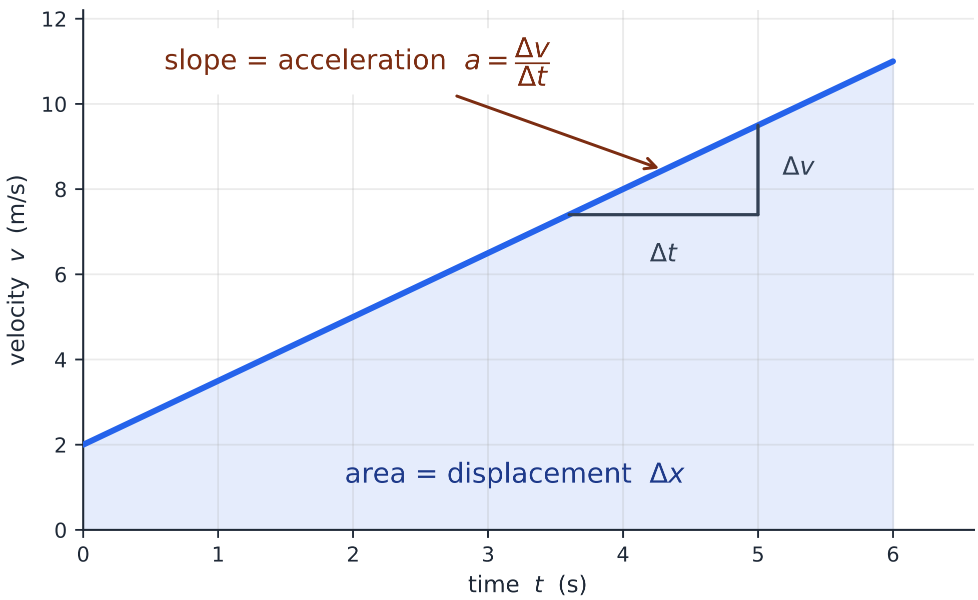
A graph shows motion at a glance. On a **position–time** graph, the **gradient** 斜率 (steepness) is the velocity.



- A flat line means the object is not moving.
- A straight slope means constant velocity (steeper = faster).
- A curve means the velocity is changing.

■ 5 Velocity–time graphs

On a **velocity–time** graph, two useful things are hidden in the shape:



- The gradient (slope) is the acceleration.
- The **area** under the line is the displacement.

Worked example. A car holds 6 m/s for 4 s. On the velocity–time graph this is a rectangle, so the displacement is $6 \times 4 = 24$ m.

> **Watch out:** a negative velocity does not mean slow – it means moving in the negative direction. Speed is the size of the velocity, so it is always positive.

Practice

Try these in order. They get a little harder. The methods are all above.

2.1 A car travels 6 km north, then 2 km south. Find (a) the distance travelled, (b) the displacement. [2]

2.2 State whether each quantity is a scalar or a vector: (a) speed, (b) velocity, (c) distance, (d) acceleration. [2]

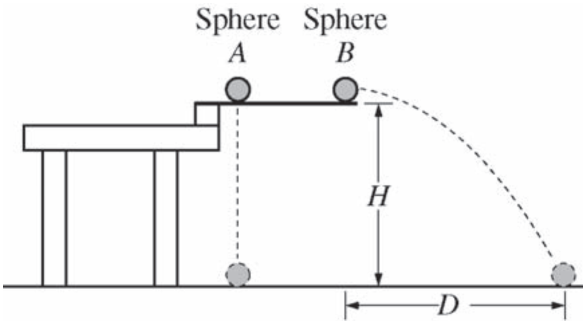
2.3 A runner covers 200 m in 25 s. Calculate the average speed. [1]

2.4 A velocity is written as −8 m/s. Explain what the minus sign tells you. [1]

2.5 A train speeds up from 5 m/s to 20 m/s in 6 s. Calculate its acceleration. [2]

2.6 A velocity–time graph shows a constant 12 m/s for 8 s. Find the displacement. [2]

2.7 On a position–time graph, describe the motion shown by (a) a flat horizontal line, (b) a straight upward slope. [2]

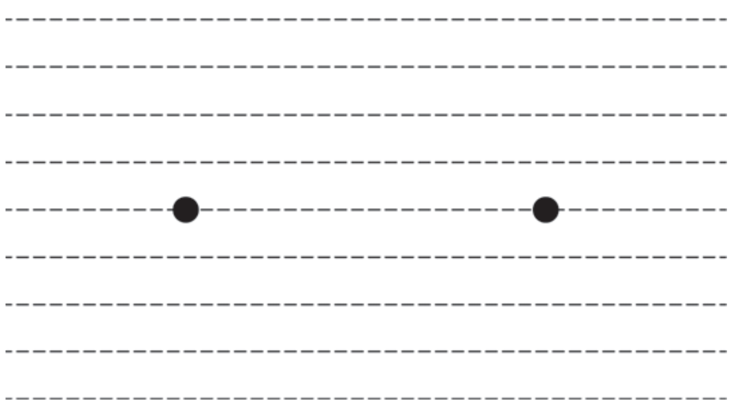


4. (7 points, suggested time 13 minutes)

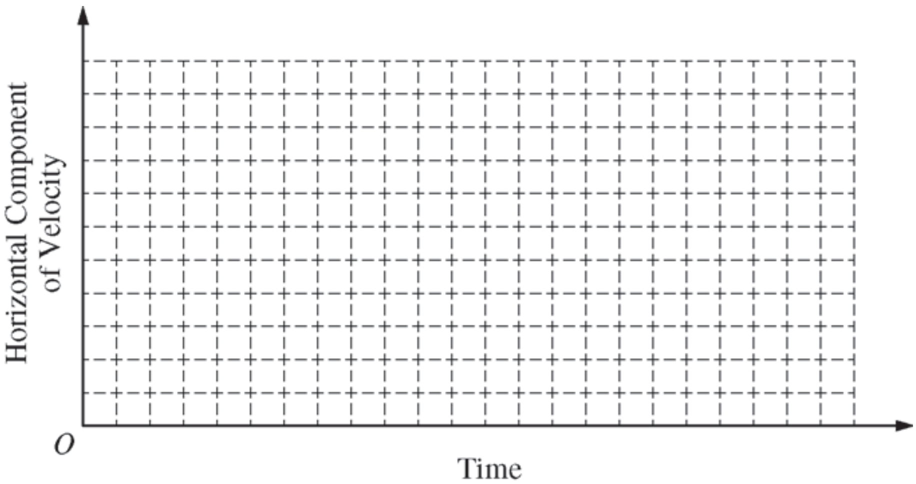
Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.

Sphere A Sphere B



(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.



(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

1 Equations of motion, free fall, and 2D motion – 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)		
air resistance	空气阻力			
acceleration due to gravity	重力加速度			
free fall	自由落体			
components	分量			
projectile	抛体			

Recall

In Part A you learned to describe motion and read graphs. Now bring two more tools:

- When velocity is constant, velocity = displacement ÷ time.
- When something speeds up steadily, you need equations that include **acceleration** – that is this sheet.
- From maths you know right-angled triangles (Pythagoras, sine, cosine). You will use them to split motion into two directions.

Take it slowly. Each idea has a worked example before the Practice.

New ideas

1 The constant-acceleration equations

When acceleration is **constant** (steady), four equations link five quantities: start velocity v_0, final velocity v, acceleration a, time t, and displacement Δx.

$$v = v_0 + at, \qquad \Delta x = v_0 t + \tfrac{1}{2}at^2, \qquad v^2 = v_0^2 + 2a\,\Delta x, \qquad \Delta x = \tfrac{1}{2}(v_0 + v)t.$$

The trick: list what you know, then pick the equation that holds your three knowns plus the one you want, so only one unknown is left.

Worked example. A car starts from rest ($v_0 = 0$) and accelerates at 2.0 m/s^2 for 6.0 s. Final velocity: $v = v_0 + at = 0 + 2.0 \times 6.0 = 12$ m/s. Distance: $\Delta x = v_0 t + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 2.0 \times 6.0^2 = 36$ m.

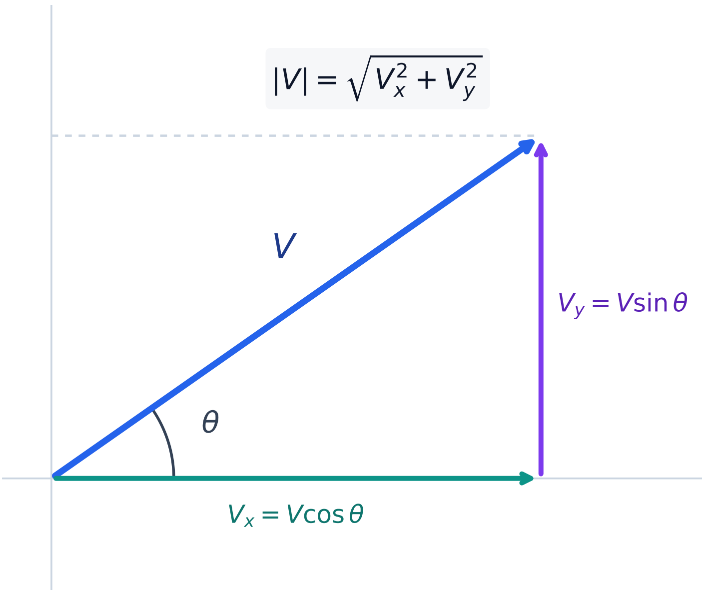
2 Free fall

Near Earth, if we ignore **air resistance** 空气阻力, everything falls with the same **acceleration due to gravity** 重力加速度 $g = 9.8$ m/s^2, pointing down. This is **free fall** 自由落体.

Worked example. A stone is dropped ($v_0 = 0$) and falls for 2.0 s. Taking down as positive: speed $v = gt = 9.8 \times 2.0 = 20$ m/s, and distance $\Delta x = \frac{1}{2}gt^2 = \frac{1}{2} \times 9.8 \times 2.0^2 = 20$ m.

3 Motion in two directions – components

A vector at an angle splits into two **components** 分量 at right angles: a horizontal part and a vertical part.



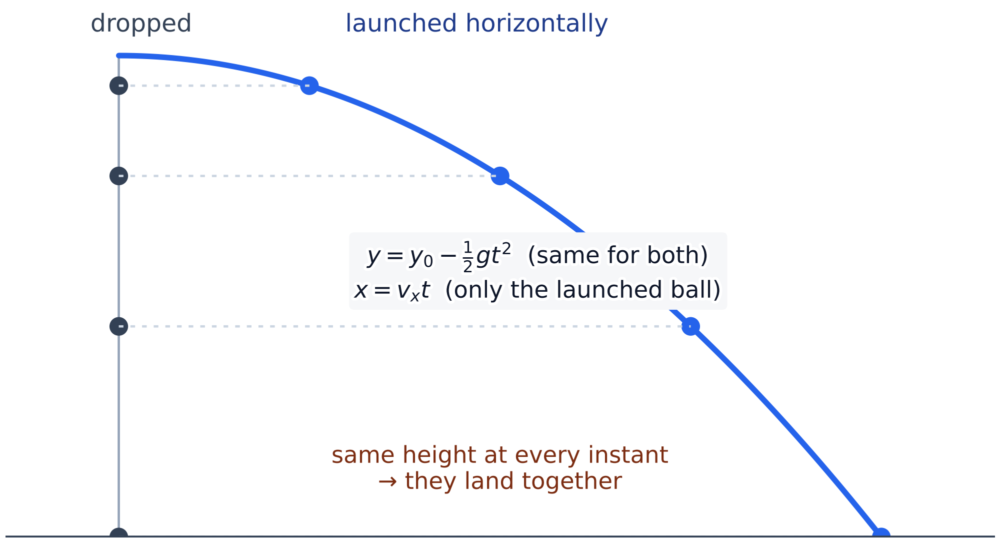
For a velocity v at angle θ above the horizontal:

$$v_x = v\cos\theta, \qquad v_y = v\sin\theta.$$

Worked example. A ball leaves at 10 m/s, 30° above the horizontal: $v_x = 10\cos 30° = 8.7$ m/s, and $v_y = 10\sin 30° = 5.0$ m/s.

4 Projectile motion

A **projectile** 抛体 moves under gravity alone. The big idea: its horizontal and vertical motions are **independent** and share only the **time**.



- Horizontal: no acceleration, so the horizontal velocity stays constant.
- Vertical: acceleration g downward, exactly like free fall.

So a ball dropped and a ball thrown sideways from the same height reach the ground **at the same moment** – their vertical motions are identical.

Watch out: the two directions share only the time. Never mix a horizontal distance with a vertical velocity in one equation – solve each direction on its own, then join them through t.

Practice

Try these in order. The methods are all above.

2.1 A car accelerates from rest at 3.0 m/s^2 for 5.0 s. Find its final velocity. [2]

2.2 Using the same car, find the distance it travels in those 5.0 s. [2]

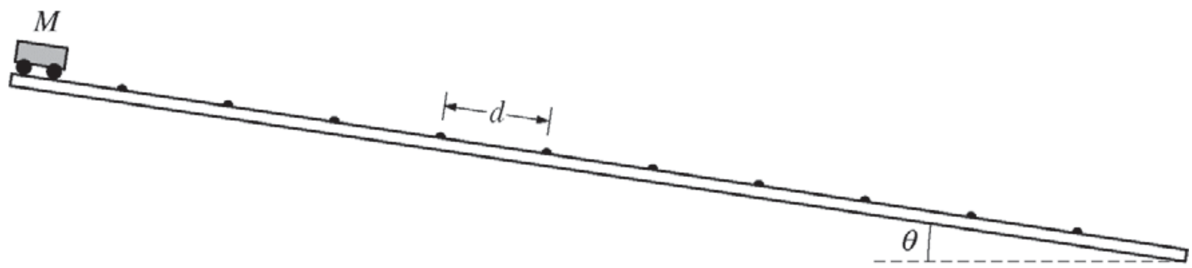
2.3 A ball is dropped from rest. Taking $g = 9.8$ m/s^2 and down as positive, find its speed after 1.5 s. [2]

2.4 A velocity of 12 m/s points 60° above the horizontal. Find its horizontal and vertical components. [2]

2.5 A stone is thrown horizontally from a cliff at the same moment another is dropped. Explain why they hit the ground at the same time. [2]

2.6 A motorbike slows from 20 m/s to 8 m/s while covering 42 m. Use $v^2 = v_0^2 + 2a\,\Delta x$

to find its acceleration. [3]



Note: Figure not drawn to scale.

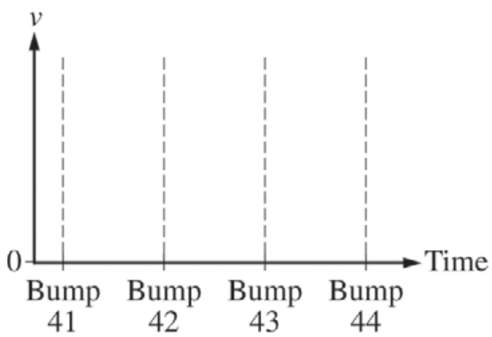
3. (12 points, suggested time 25 minutes)

A long track, inclined at an angle θ to the horizontal, has small speed bumps on it. The bumps are evenly spaced a distance d apart, as shown in the figure above. The track is actually much longer than shown, with over 100 bumps. A cart of mass M is released from rest at the top of the track. A student notices that after reaching the 40th bump the cart's average speed between successive bumps no longer increases, reaching a maximum value v_{avg}. This means the time interval taken to move from one bump to the next bump becomes constant.

(a) Consider the cart's motion between bump 41 and bump 44.

i. In the figure below, sketch a graph of the cart's velocity v as a function of time from the moment it reaches bump 41 until the moment it reaches bump 44.

ii. Over the same time interval, draw a dashed horizontal line at $v = v_{avg}$. Label this line "v_{avg}".



(b) Suppose the distance between the bumps is increased but everything else stays the same.

Is the maximum speed of the cart now greater than, less than, or the same as it was with the bumps closer together?

____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

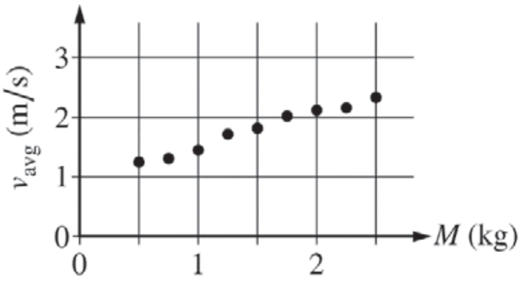
(c) With the bumps returned to the original spacing, the track is tilted to a greater ramp angle θ. Is the maximum speed of the cart greater than, less than, or the same as it was when the ramp angle was smaller?

____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

(d) Before deriving an equation for a quantity such as v_{avg}, it can be useful to come up with an equation that is intuitively expected to be true. That way, the derivation can be checked later to see if it makes sense physically. A student comes up with the following equation for the cart's maximum average speed: $v_{avg} = C\dfrac{Mg\sin\theta}{d}$, where C is a positive constant.

i. To test the equation, the student rolls a cart down the long track with speed bumps many times in front of a motion detector. The student varies the mass M of the cart with each trial but keeps everything else the same. The graph shown below is the student's plot of the data for v_{avg} as a function of M.



Are these data consistent with the student's equation?

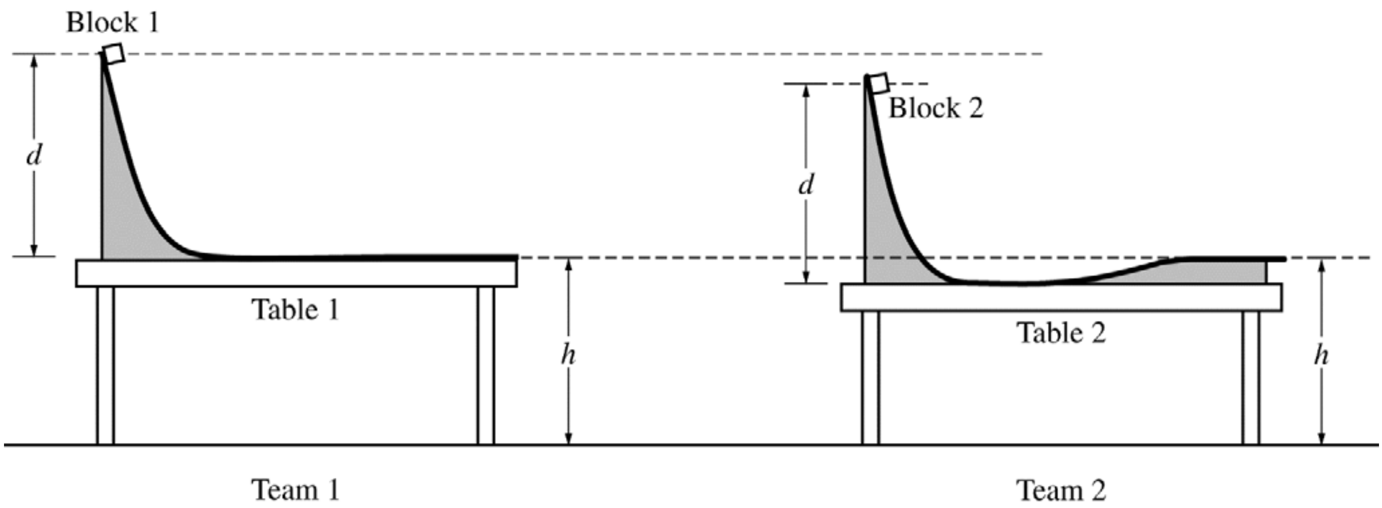
____ Yes ____ No

Briefly explain your reasoning.

ii. Another student suggests that whether or not the data above are consistent with the equation, the equation could be incorrect for other reasons. Does the equation make physical sense?

____ Yes ____ No

Briefly explain your reasoning.



4. (7 points, suggested time 13 minutes)

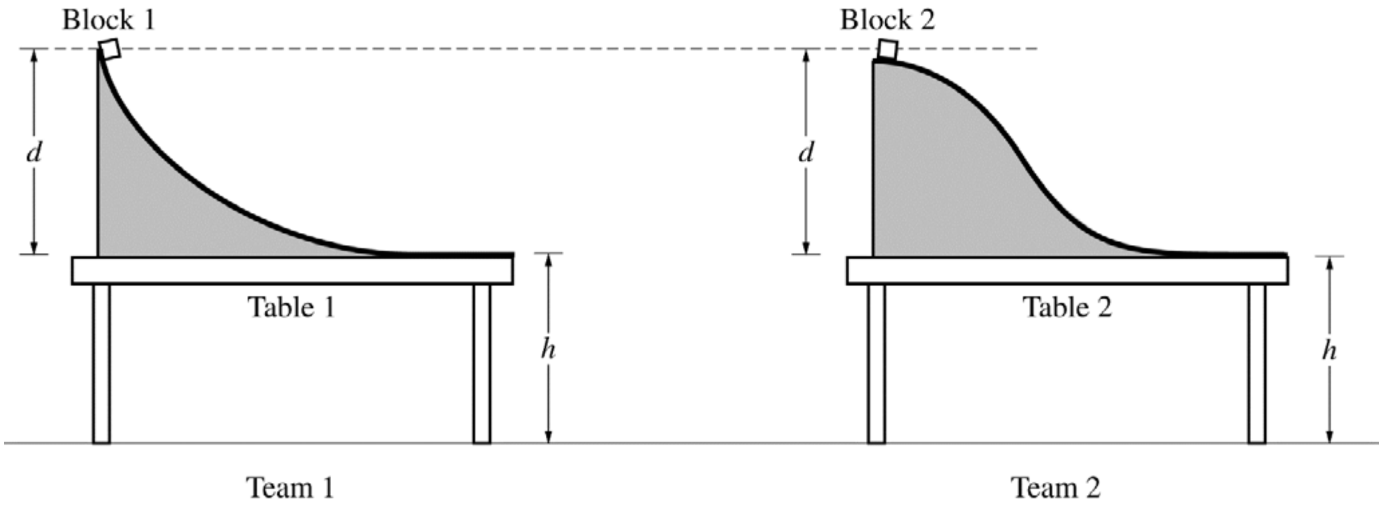
A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

(a) Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

____ Yes ____ No

Justify your answer.

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.



(b) Both blocks are released from rest at the top of their respective slides at the same time.

i. Which block, if either, lands farther from its respective table?

____ Block 1 ____ Block 2 ____ The two blocks land the same distance from their respective tables.

Briefly explain your reasoning without manipulating equations.

ii. Which block, if either, hits the floor first?

____ Block 1 ____ Block 2 ____ The two blocks hit the floor at the same time.

Briefly explain your reasoning without manipulating equations.

2 Forces and Newton's laws – 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)		
force	力			
free-body diagram	受力图			
Weight	重力			
Newton's first law	牛顿第一定律			
inertia	惯性			
net force	合力			
equilibrium	平衡			
Newton's second law	牛顿第二定律			
Newton's third law	牛顿第三定律			

Recall

You have met forces before. Bring these ideas with you:

- A **force** is a push or a pull, measured in newtons (N).
- Gravity pulls things down; a table pushes up; a rope pulls along its length.
- You know that a heavier object is harder to get moving. At AP we make this exact with **Newton's laws**.

Nothing here is harder than what you already know – we just line it up carefully and draw good diagrams.

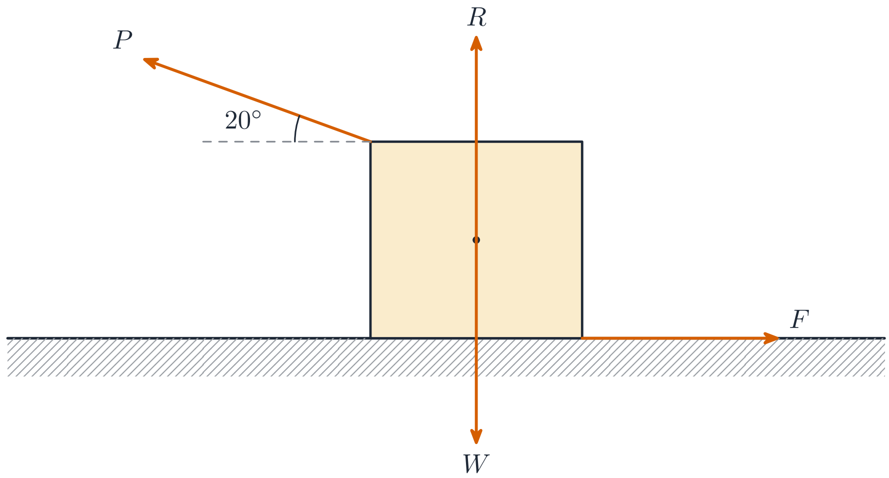
New ideas

Read these first. Each idea has a short worked example. Then do the Practice below.

1 Force and the free-body diagram

A **force** 力 is a push or pull. It is a vector, so it has a size **and** a direction.

To solve any force problem, first draw a **free-body diagram** 受力图: show the object as a dot, then draw an arrow for **every** force acting **on** it – weight down, the surface's push, any rope or hand.



Two rules keep it honest: draw only forces acting **on** your object (not forces it pushes on other things), and draw only **real** forces (a rope, a surface, gravity) – never an "ma" arrow.

2 Weight

Weight 重力 is the force of gravity on an object: $F_g = mg$, pointing down. Here m is the mass and $g = 9.8\ \text{m/s}^2$ near Earth.

Worked example. A 2.0 kg bag has weight $F_g = mg = 2.0 \times 9.8 = 19.6$ N. On the Moon ($g = 1.6\ \text{m/s}^2$) the same bag weighs only $2.0 \times 1.6 = 3.2$ N – but its **mass** is still 2.0 kg.

3 Newton's first law

Newton's first law 牛顿第一定律 (the law of **inertia** 惯性): an object keeps a constant velocity unless a **net force** 合力 acts on it. So if the forces balance to zero, the object stays at rest or keeps moving at steady speed – it is in **equilibrium** 平衡.

Worked example. A car moves at a steady 25 m/s. Because the velocity is constant, the net force is zero – the engine's push exactly balances friction and air drag.

■ 4 Newton's second law

When the net force is **not** zero, the object accelerates: **Newton's second law** 牛顿第二定律 says

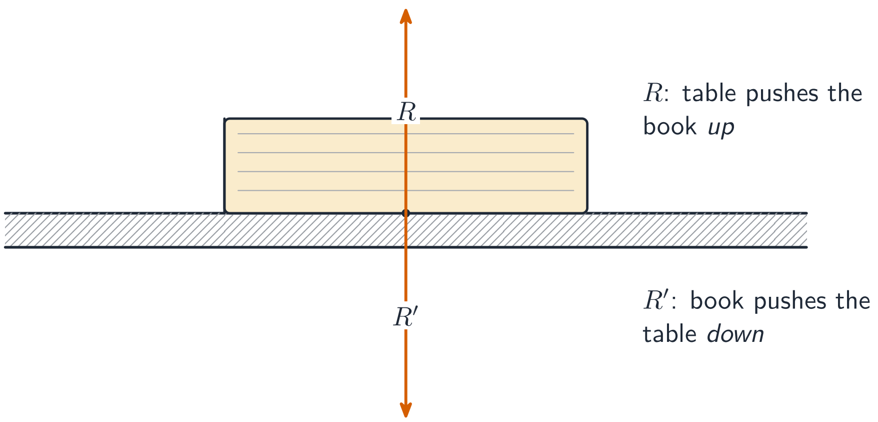
$$a = \frac{\sum F}{m}, \qquad \text{so} \qquad \sum F = ma.$$

The acceleration points the same way as the net force.

Worked example. A 4.0 kg box is pulled with 18 N while friction pulls back 6.0 N. The net force is $18 - 6.0 = 12$ N, so $a = \dfrac{12}{4.0} = 3.0\ \mathrm{m/s^2}$.

■ 5 Newton's third law

Newton's third law 牛顿第三定律: if A pushes on B, then B pushes back on A with an **equal and opposite** force.



The two forces act on **different** objects, so they never cancel.

Watch out: a book's weight and the table's push on the book are **not** a third-law pair – they act on the **same** object (the book). A third-law pair is always "A on B" with "B on A."

Practice

Try these in order. The methods are all above.

2.1 State the size and direction of the weight of a 3.0 kg book ($g = 9.8$ m/s^2). [2]

2.2 A box rests on a table. Name the two forces on the box and state their directions. [2]

2.3 A 6.0 kg trolley is pushed with a net force of 18 N. Find its acceleration. [2]

2.4 A lift moves upward at a **constant** speed. What is the net force on it? Explain. [2]

2.5 A 2.0 kg ball is pulled by a 10 N force while a 4.0 N friction force opposes it. Find the acceleration. [2]

2.6 A student says "the ground pushes up on my feet, and my feet push down on the ground – these cancel out, so I feel nothing." State what is wrong with this reasoning. [2]

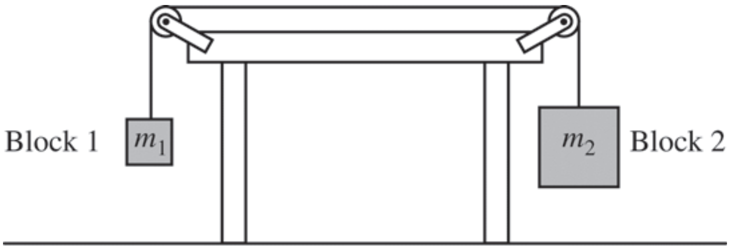
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

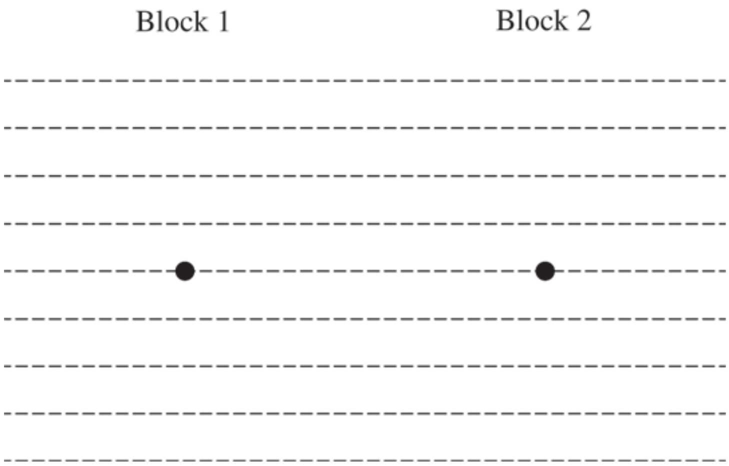


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

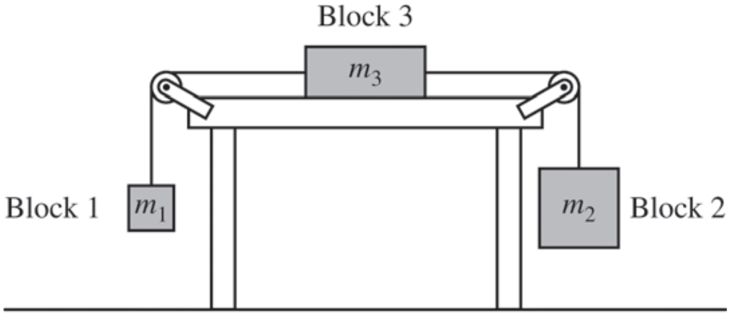
   Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

   (a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



   (b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

2. (12 points, suggested time 25 minutes)

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

ii. Describe the overall procedure to be used, including any steps necessary to reduce experimental uncertainty. Give enough detail so that another student could replicate the experiment.

(b) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

____ The static and kinetic coefficients are equal.

____ The static and kinetic coefficients are not equal.

Briefly justify your reasoning.

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

____ Increase ____ Decrease ____ Remain the same

Briefly state your reasoning.

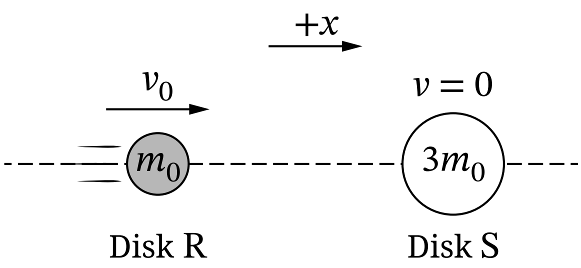
Question 2: Version J

2. Two small disks, R and S, are on a straight, horizontal track.

At time $t = 0$, Disk R of mass m_0 is located at position $x = 0$. Disk R is initially moving with speed v_0 in the $+x$-direction. Disk S of mass $3m_0$ is initially at rest, as shown in the top view in Figure 1. Frictional forces are negligible.

At $t = t_1$, the disks collide. Immediately after the collision, Disk R moves with speed $\frac{1}{2}v_0$ in the $-x$-direction.

Figure 1



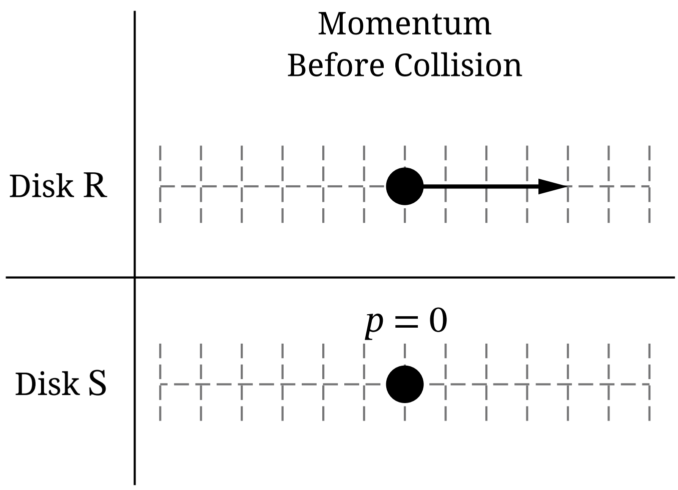
Top View

Note: Figure not drawn to scale.

Part A

The momentum-vector diagram in Figure 2 represents the momentums of Disk R and Disk S before the collision.

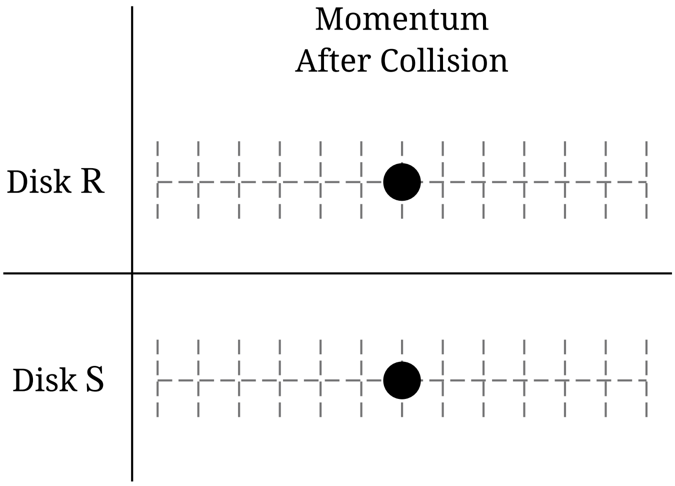
Figure 2



Draw arrows on Figure 3 to represent the momentum vectors of Disk R and Disk S after the collision.

- Each arrow must start on, and point away from, each dot.
- If the momentum of either disk is zero, write "$p = 0$" next to the dot.
- Draw the length of each arrow to represent the magnitude of each momentum, consistent with the scale used in Figure 2.

Figure 3



Part B

Starting with conservation of linear momentum, **derive** an expression for the kinetic energy of Disk S immediately after the collision. Express your final answer in terms of m_0, v_0, and physical constants, as appropriate. Begin your derivation by writing the fundamental physics principle or an equation from the reference information.

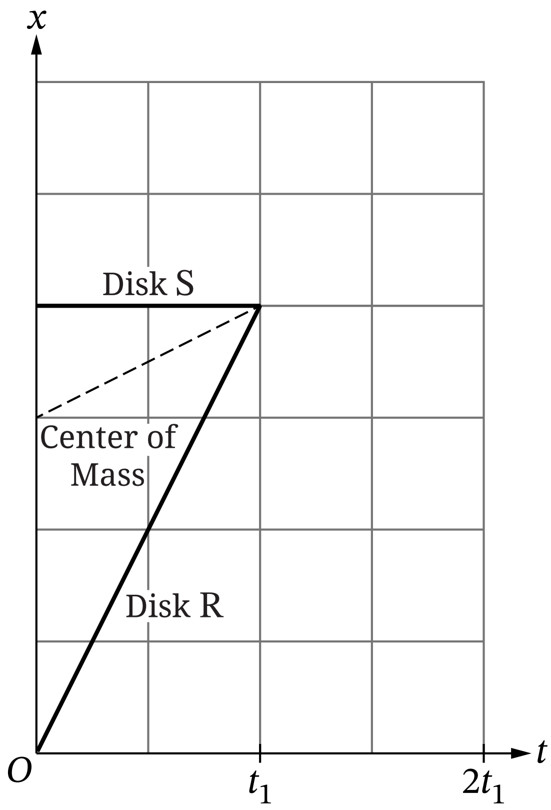
Part C

The graph shown in Figure 4 represents the positions x as functions of time t from $t = 0$ until $t = t_1$ for each of the following:

- Disk R
- Disk S
- The center of mass of the two-disk system

On the graph shown in Figure 4, **draw** three lines that represent the positions x of Disk R, Disk S, and the center of mass of the two-disk system as functions of t from $t = t_1$ to $t = 2t_1$. Distinctly **label** each line.

Figure 4



Part D

During the collision, the magnitudes of the changes in momentum of Disk R and Disk S are $|\Delta p_R|$ and $|\Delta p_S|$, respectively.

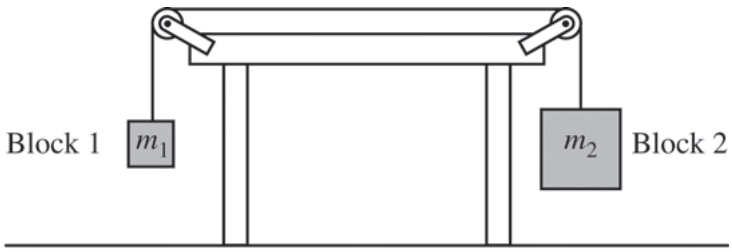
Indicate whether $|\Delta p_R|$ is greater than, less than, or equal to $|\Delta p_S|$ by writing one of the following.

- $|\Delta p_R| > |\Delta p_S|$
- $|\Delta p_R| < |\Delta p_S|$
- $|\Delta p_R| = |\Delta p_S|$

Briefly **justify** your response by referencing a fundamental physics principle.

PHYSICS 1
Section II
5 Questions
Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.



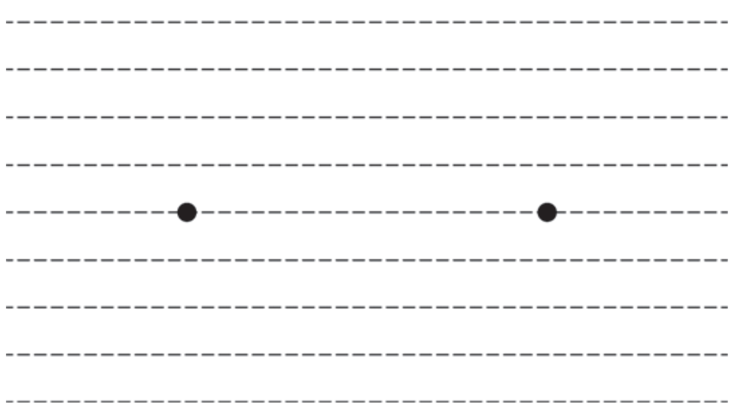
Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

   Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

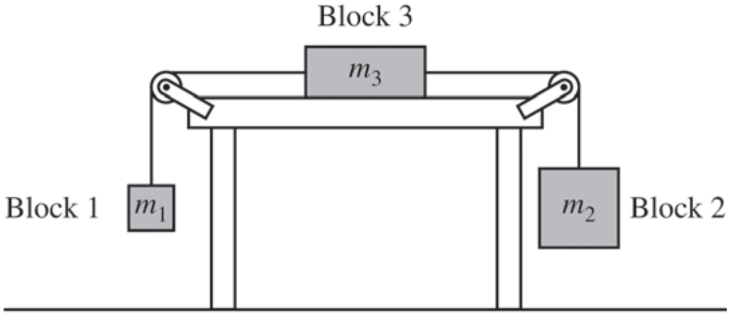
   (a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.

   Block 1 Block 2



   (b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

2 Friction, springs, and circular motion – 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)		
normal force	法向力			
Friction	摩擦力			
Static friction	静摩擦			
Kinetic friction	动摩擦			
coefficient of friction	摩擦系数			
Hooke's law	胡克定律			
spring constant	弹簧常数			
centripetal acceleration	向心加速度			
centripetal force	向心力			

Recall

In Part A you drew free-body diagrams and used $\sum F = ma$. Now meet three everyday forces that appear again and again:

- **Friction** slows sliding – you feel it when you drag a heavy box.
- A **spring** pulls back when you stretch it.
- Anything moving in a **circle** needs a force pulling it inward.

Each idea below has a worked example before the Practice.

New ideas

1 The normal force

When an object rests on a surface, the surface pushes back at right angles to it. This is the **normal force** 法向力 N. On a flat floor it balances the weight, so $N = mg$.

Worked example. A 5.0 kg box on a level floor has $N = mg = 5.0 \times 9.8 = 49$ N.

2 Friction

Friction 摩擦力 acts along a surface and opposes sliding. It comes in two kinds:

- **Static friction** 静摩擦 (before sliding) adjusts itself up to a maximum $f_s \le \mu_s N$ to stop motion starting.
- **Kinetic friction** 动摩擦 (while sliding) is $f_k = \mu_k N$.

Here μ is the **coefficient of friction** 摩擦系数 (a number for how rough the contact is).

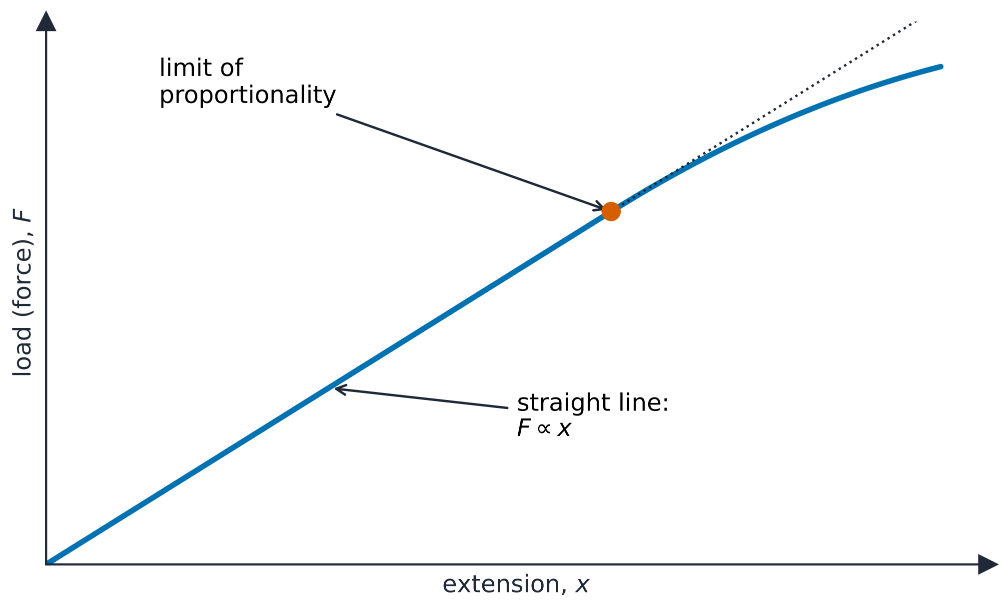
Worked example. A crate with $N = 49$ N and $\mu_s = 0.40$ needs a push above $f_{s,\max} = \mu_s N = 0.40 \times 49 = 19.6$ N to start moving. A 15 N push is too small, so it stays still.

3 Springs and Hooke's law

A spring pulls (or pushes) back toward its natural length. **Hooke's law** 胡克定律 says the force is proportional to the stretch x:

$$F_s = kx,$$

where k is the **spring constant** 弹簧常数 (its stiffness).

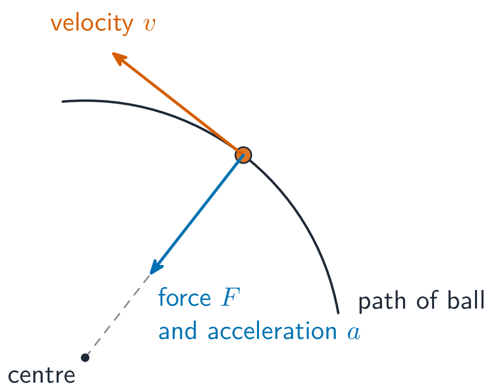


Worked example. A spring with $k = 200$ N/m holds a 0.50 kg mass at rest. The spring force balances the weight, $kx = mg$, so $x = \dfrac{mg}{k} = \dfrac{0.50 \times 9.8}{200} = 0.025$ m $= 2.5$ cm.

■ 4 Circular motion

An object moving in a circle at steady speed is still **accelerating**, because its direction keeps changing. This **centripetal acceleration** 向心加速度 points to the centre:

$$a_c = \frac{v^2}{r}.$$



It is caused by a real inward **centripetal force** 向心力 $F_c = \dfrac{mv^2}{r}$ – supplied by tension, gravity, or friction.

Watch out: there is no outward "centrifugal" force pulling you out of the circle. The only force is the real one pulling you **inward**; you feel pushed out only because your body wants to keep going straight.

Practice

Try these in order. The methods are all above.

2.1 A 4.0 kg block sits on a flat floor. Find the normal force on it ($g = 9.8\ \text{m/s}^2$). [2]

2.2 Using that block, the coefficient of static friction is $\mu_s = 0.30$. Find the largest static friction force before it slides. [2]

2.3 A spring stretches 0.040 m when a 12 N force pulls it. Find the spring constant k. [2]

2.4 Explain why an object going around a circle at constant speed is still accelerating. [2]

2.5 A 0.30 kg ball is whirled in a circle of radius 0.80 m at 4.0 m/s. Find the centripetal force needed. [3]

2.6 A student says a car turning a corner is pushed **outward** by a force. Correct this statement. [2]

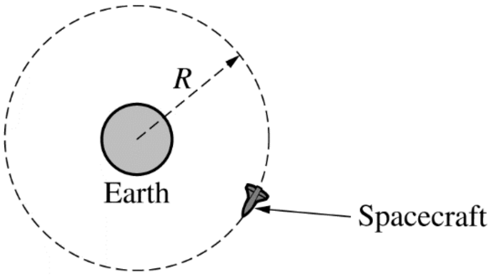
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

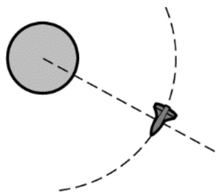


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

   A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

   (a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

   (b)

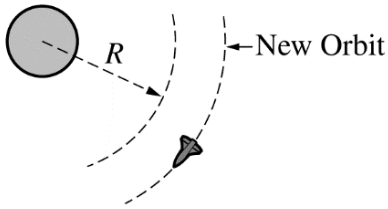
   i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

   ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

   ____ Greater than ____ Less than ____ Equal to

   Briefly explain your reasoning.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

2. (12 points, suggested time 25 minutes)

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

ii. Describe the overall procedure to be used, including any steps necessary to reduce experimental uncertainty. Give enough detail so that another student could replicate the experiment.

(b) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

____ The static and kinetic coefficients are equal.

____ The static and kinetic coefficients are not equal.

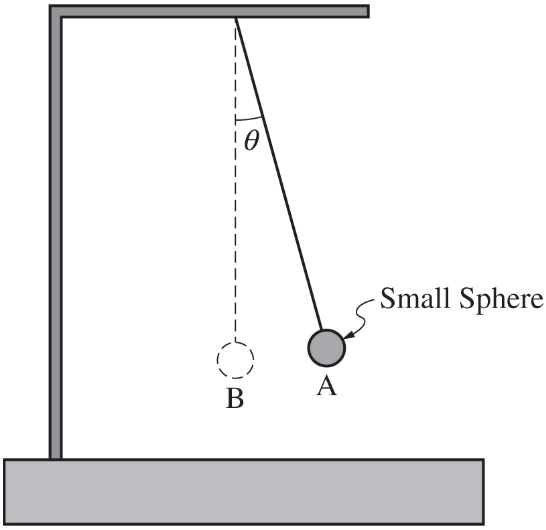
Briefly justify your reasoning.

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

____ Increase ____ Decrease ____ Remain the same

Briefly state your reasoning.

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



4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E.

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(a) **Justify** why W_X is less than W_E.

GO ON TO THE NEXT PAGE.

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

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E.

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y.

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E.

GO ON TO THE NEXT PAGE.

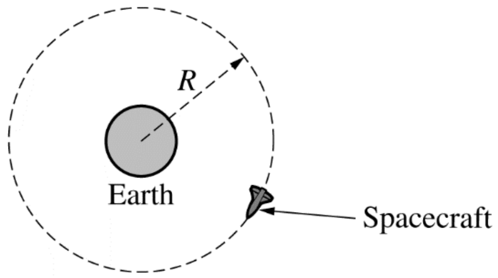
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

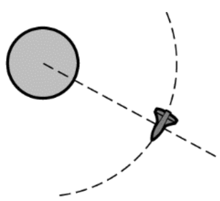


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

(b)

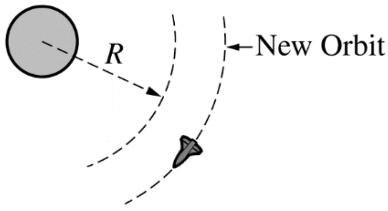
i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

3 Work, kinetic energy, and potential energy – 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)		
Energy	能量			
joules	焦耳			
kinetic energy	动能			
Work	功			
work–energy theorem	动能定理			
Potential energy	势能			
Gravitational potential energy	重力势能			
Elastic potential energy	弹性势能			

Recall

You already know a lot about energy:

- Energy comes in forms – movement, height, heat, light – and can change from one form to another.
- You cannot make energy from nothing or destroy it; it is only moved around.
- You met the idea that a fast or heavy object carries more energy. At AP we make this exact with formulas.

Each idea below has a worked example. Then do the Practice.

New ideas

■ 1 Kinetic energy

Energy 能量 is the capacity to do work, measured in **joules 焦耳** (J). A moving object has **kinetic energy 动能**:

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

It depends on the **square** of the speed, so doubling the speed makes the kinetic energy **four times** larger.

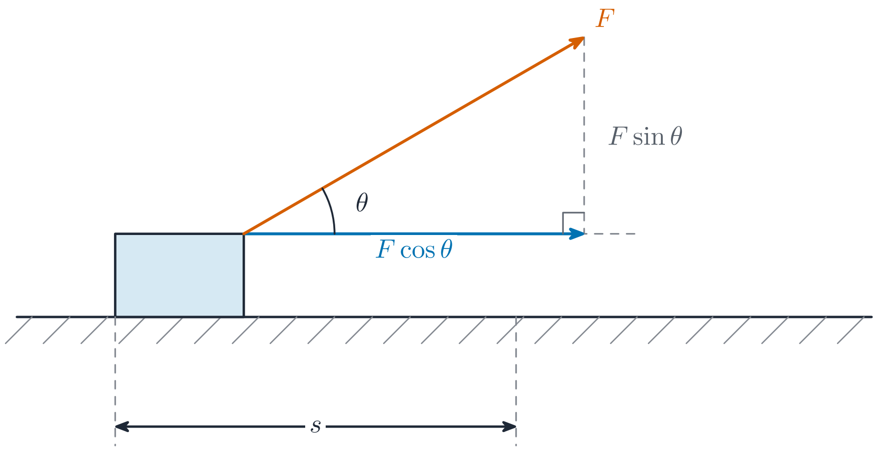
Worked example. A 1500 kg car at 20 m/s has $K = \frac{1}{2} \times 1500 \times 20^2 = 3.0 \times 10^5$ J. At 40 m/s it is four times as much.

■ 2 Work

Work 功 is energy transferred when a force pushes something through a distance:

$$W = Fd\cos\theta,$$

where θ is the angle between the force and the movement. Work is **positive** if the force helps the motion, **negative** if it opposes it, and **zero** if the force is at right angles to the motion.



Worked example. A 20 N force pushes a box 3.0 m in its own direction: $W = Fd = 20 \times 3.0 = 60$ J.

■ 3 The work–energy theorem

The net work done on an object equals the change in its kinetic energy – the **work–energy theorem 动能定理**:

$$W_{\text{net}} = \Delta K.$$

Worked example. If 60 J of net work is done on a resting 3.0 kg trolley, then $60 = \frac{1}{2} \times 3.0 \times v^2$, giving $v^2 = 40$ and $v = 6.3$ m/s.

■ 4 Potential energy

Potential energy 势能 is stored energy that depends on position:

- **Gravitational potential energy** 重力势能 (from height h): $U_g = mgh$.
- **Elastic potential energy** 弹性势能 (in a stretched spring): $U_s = \frac{1}{2}kx^2$.

Worked example. Lifting a 2.0 kg book 1.5 m stores $U_g = mgh = 2.0 \times 9.8 \times 1.5 = 29.4$ J.

Watch out: carrying a bag horizontally at steady height does **no** work on the bag – the lifting force is vertical but the movement is horizontal, so $\cos 90° = 0$.

Practice

Try these in order. The methods are all above.

2.1 Find the kinetic energy of a 0.50 kg ball moving at 6.0 m/s. [2]

2.2 A 40 N force pushes a crate 5.0 m in its own direction. Find the work done. [2]

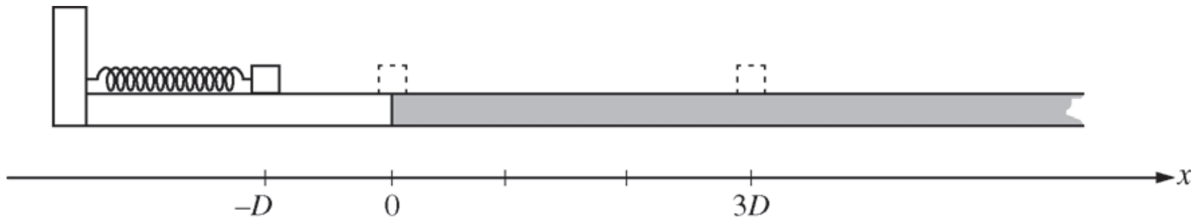
2.3 State whether the work is positive, negative, or zero when (a) friction acts on a sliding box, (b) you carry a box horizontally at constant height. [2]

2.4 A 3.0 kg mass is lifted 2.0 m. Find the gain in gravitational potential energy ($g =$

9.8 m/s^2). [2]

2.5 A 2.0 kg trolley starts at rest. A net work of 36 J is done on it. Use the work–energy theorem to find its final speed. [3]

2.6 A car's speed triples. By what factor does its kinetic energy increase? [1]



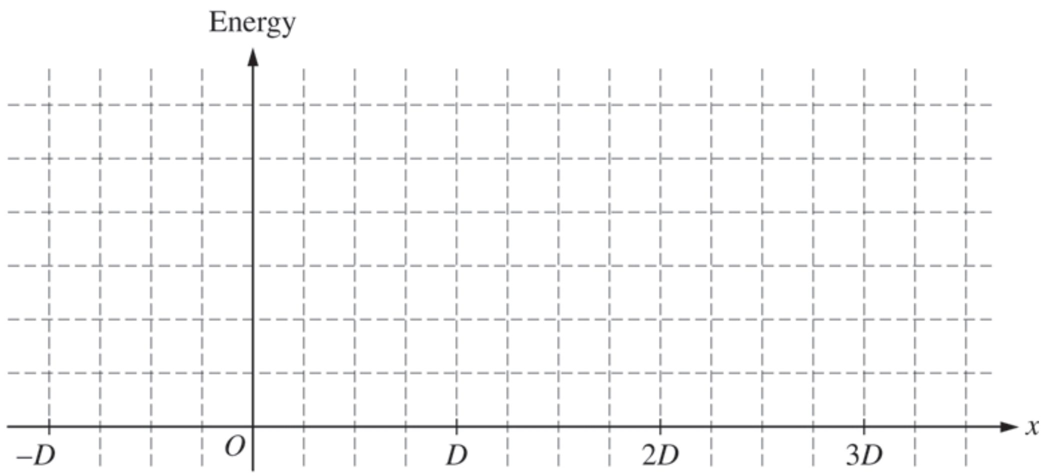
3. (12 points, suggested time 25 minutes)

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

ii. The potential energy U of the block-spring system



The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

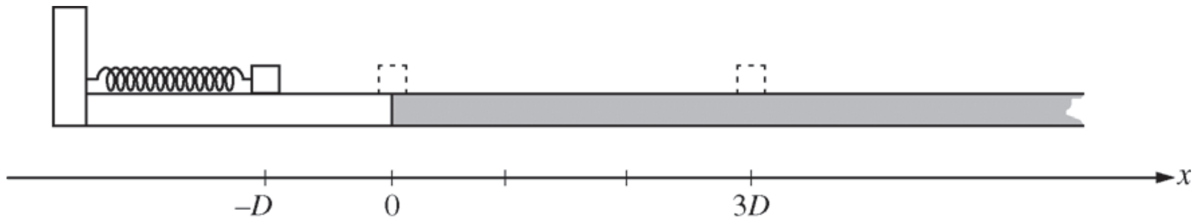
(b)

i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.

ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.



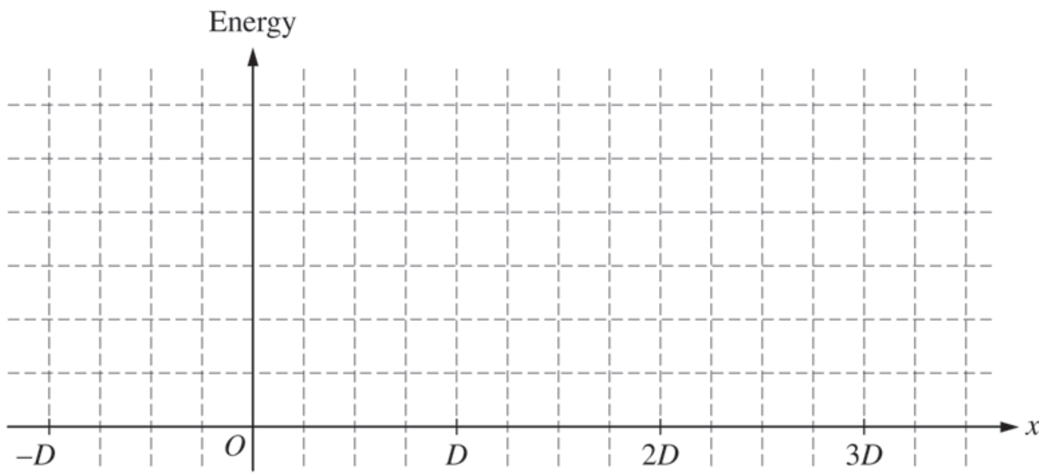
3. (12 points, suggested time 25 minutes)

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

ii. The potential energy U of the block-spring system



The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

(b)

i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.

ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.

3 Conservation of energy and power – 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)		
mechanical energy	机械能			
conserved	守恒			
thermal energy	热能			
Power	功率			
watts	瓦特			
efficiency	效率			

Recall

In Part A you met kinetic energy $K = \frac{1}{2}mv^2$ and potential energy $U = mgh$. Now put them together:

- Energy is never lost – it only changes form.
- A falling ball speeds up (gains K) as it drops (loses U).
- Doing the same job faster needs more **power** – that is the last idea on this sheet.

Each idea has a worked example before the Practice.

New ideas

1 Mechanical energy

The **mechanical energy** 机械能 of an object is its kinetic plus potential energy:

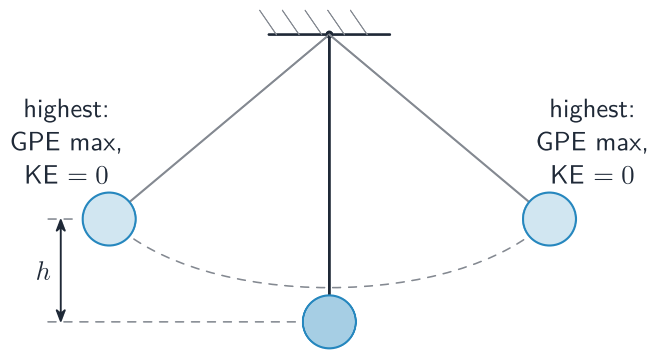
$$E = K + U.$$

2 Conservation of energy

When only gravity and springs act (no friction), the mechanical energy is **conserved** 守恒 – it stays the same:

$$K_1 + U_1 = K_2 + U_2.$$

So energy lost from one form appears in another.



Worked example. A ball is released from rest at the top of a smooth ramp 5.0 m high. All its potential energy becomes kinetic: $mgh = \frac{1}{2}mv^2$, so $v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 5.0} = 9.9$ m/s. The mass cancels, so every object reaches the same speed.

3 When friction acts

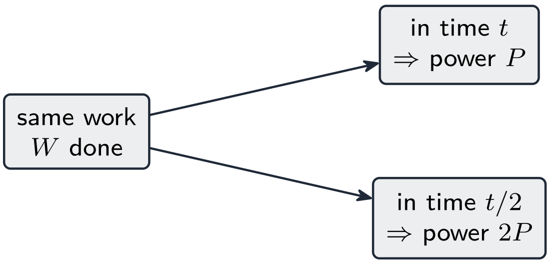
Friction turns mechanical energy into **thermal energy** 热能 (heat). Then energy is still conserved overall, but some has left the "useful" $K + U$ pool.

Worked example. If the ramp above loses 30 J to friction, you subtract it: $mgh - 30 = \frac{1}{2}mv^2$.

4 Power

Power 功率 is the **rate** of transferring energy, measured in **watts** 瓦特 (W):

$$P = \frac{W}{\Delta t}, \qquad \text{and at steady speed} \qquad P = Fv.$$



$$P = \frac{W}{t} \text{ — less time, more power}$$

Worked example. A motor lifts a 50 kg load at a steady 2.0 m/s. The force equals the weight, so $P = Fv = mgv = 50 \times 9.8 \times 2.0 = 980$ W.

■ 5 Efficiency

Real machines waste some energy, so we quote **efficiency** 效率 – useful output divided by total input:

$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}}.$$

Worked example. A motor that draws 1400 W but delivers 980 W of useful lifting is $\frac{980}{1400} = 0.70 = 70\%$ efficient.

Watch out: at constant speed the net force is zero, but power is **not** zero – the motor still does work against gravity or friction. "Balanced forces" does not mean "no energy used."

Practice

Try these in order. The methods are all above.

2.1 A 0.20 kg ball is dropped from 1.8 m. Using energy conservation, find its speed just before it lands ($g = 9.8$ m/s^2). [3]

2.2 State the energy change as a pendulum swings from its highest point down to its lowest point. [2]

2.3 A crane does 6000 J of work in 4.0 s. Find its power output. [2]

2.4 A machine takes in 500 W and delivers 300 W of useful power. Find its efficiency as a percentage. [2]

2.5 A ball rolls down a smooth slope 2.0 m high but 15 J is lost to friction. If the ball's mass is 1.0 kg, find its speed at the bottom. [3]

2.6 Explain why a car moving at constant speed still uses fuel (energy), even though the net force on it is zero. [2]

2. (12 points, suggested time 25 minutes)

Some students want to know what gets used up in an incandescent lightbulb when it is in series with a resistor: current, energy, or both. They come up with the following two questions.

(1) In one second, do fewer electrons leave the bulb than enter the bulb?
(2) Does the electric potential energy of electrons change while inside the bulb?

The students have an adjustable power source, insulated wire, lightbulbs, resistors, switches, voltmeters, ammeters, and other standard lab equipment. Assume that the power supply and voltmeters are marked in 0.1 V increments and the ammeters are marked in 0.01 A increments.

(a) Describe an experimental procedure that could be used to answer questions (1) and (2) above. In your description, state the measurements you would make and how you would use the equipment to make them. Include a neat, labeled diagram of your setup.

(b)
i. Explain how data from the experiment you described can be used to answer question (1) above.
ii. Explain how data from the experiment you described can be used to answer question (2) above.

A lightbulb is nonohmic if its resistance changes as a function of current. Your setup from part (a) is to be used or modified to determine whether the lightbulb is nonohmic.

(c)
i. How, if at all, does the setup need to be modified?
ii. What additional data, if any, would need to be collected?

(d) How would you analyze the data to determine whether the bulb is nonohmic? Include a discussion of how the uncertainties in the voltmeters and ammeters would affect your argument for concluding whether the resistor is nonohmic.

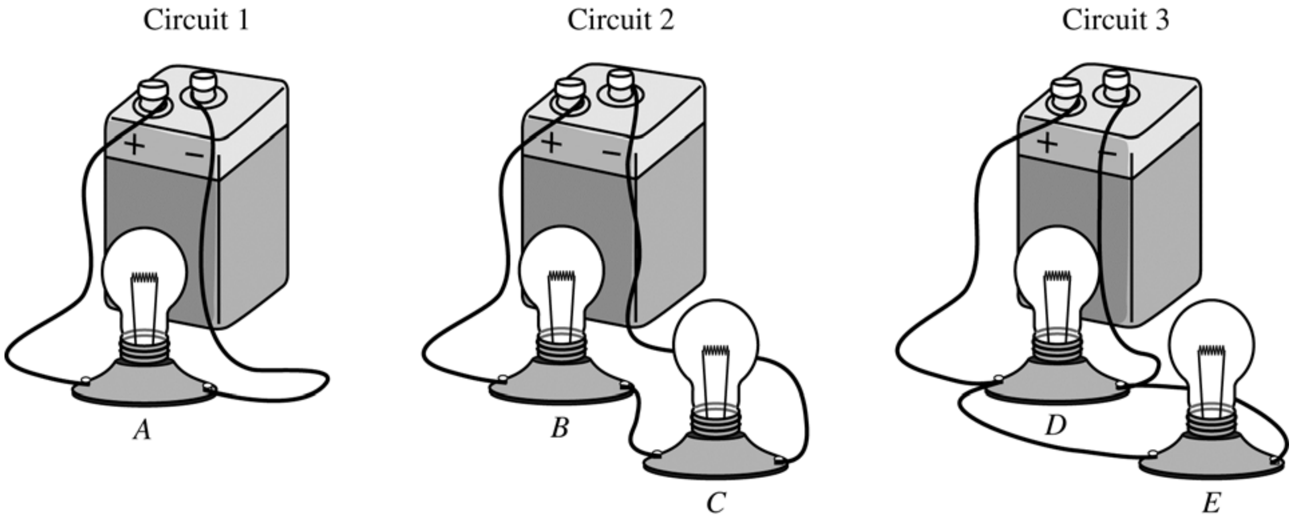
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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. (7 points, suggested time 13 minutes)

In the three circuits shown above, the batteries are all identical, and the lightbulbs are all identical. In circuit 1 a single lightbulb is connected to the battery. In circuits 2 and 3, two lightbulbs are connected to the battery in different ways, as shown. The lightbulbs are labeled *A*–*E*.

(a) Rank the magnitudes of the potential differences across lightbulbs *A*, *B*, *C*, *D*, and *E* from largest to smallest. If any lightbulbs have the same potential difference across them, state that explicitly.

Ranking:

Briefly explain how you determined your ranking.

(b) The batteries all start with an identical amount of usable energy and are all connected to the lightbulbs in the circuits at the same time.

In which circuit will the battery run out of usable energy first?

____ Circuit 1 ____ Circuit 2 ____ Circuit 3

In which circuit will the battery run out of usable energy last?

____ Circuit 1 ____ Circuit 2 ____ Circuit 3

In a clear, coherent paragraph-length response that may also contain equations and drawings, explain your reasoning.

4 Momentum and impulse – 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)		
Linear momentum	动量			
impulse	冲量			

Recall

You already have a feel for momentum, even without the word:

- A heavy truck is harder to stop than a bicycle at the same speed.
- A fast ball hurts more than a slow one when you catch it.
- Catching a ball gently (moving your hands back) hurts less. This sheet explains why, exactly.

Each idea has a worked example before the Practice.

New ideas

■ 1 Momentum

Linear momentum 动量 is mass times velocity – a vector pointing the same way as the velocity:

$$p = mv.$$

It measures how hard something is to stop. Its unit is kg m/s.

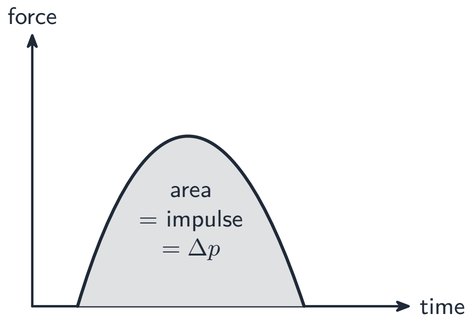
Worked example. A 0.40 kg ball moving at 5.0 m/s has momentum $p = mv = 0.40 \times 5.0 = 2.0$ kg m/s.

2 Impulse

A force acting for a time changes the momentum. The **impulse 冲量** is

$$J = F\,\Delta t,$$

and it equals the change in momentum: $J = \Delta p$. This is the **impulse–momentum theorem**.



Worked example. A 12 N force pushes a trolley for 3.0 s: impulse $= F\Delta t = 12 \times 3.0 =$ 36 kg m/s, so the momentum increases by 36 kg m/s.

3 Why time matters

Because $F = \dfrac{\Delta p}{\Delta t}$, spreading the same momentum change over a **longer time** makes the force **smaller**. That is exactly how airbags, crash mats and bending your knees on landing protect you.

Worked example. A 0.15 kg ball hits a wall at 20 m/s and bounces back at 15 m/s; contact lasts 0.020 s. Taking the rebound direction as positive, $\Delta p = m(v - u) =$ $0.15(15 - (-20)) = 5.25$ kg m/s, so $F = \dfrac{\Delta p}{\Delta t} = \dfrac{5.25}{0.020} = 260$ N.

Watch out: when a ball **bounces back**, its velocity **reverses sign**, so the change in momentum is large. Forgetting the sign flip is the most common mistake here.

Practice

Try these in order. The methods are all above.

2.1 Find the momentum of a 2.0 kg ball moving at 6.0 m/s. [2]

2.2 A 5.0 N force acts on a cart for 4.0 s. Find the impulse. [2]

2.3 The cart in 2.2 started at rest with mass 2.0 kg. Find its final speed. [2]

2.4 Explain, using impulse, why bending your knees when landing from a jump reduces the force on your legs. [2]

2.5 A 0.20 kg ball moving at 8.0 m/s is caught and stopped in 0.50 s. Find the average force on it. [3]

2.6 A ball hits a wall at 10 m/s and rebounds at 10 m/s. Its mass is 0.25 kg. Find the size of the change in momentum. [2]

Begin your response to **QUESTION 2** on this page.

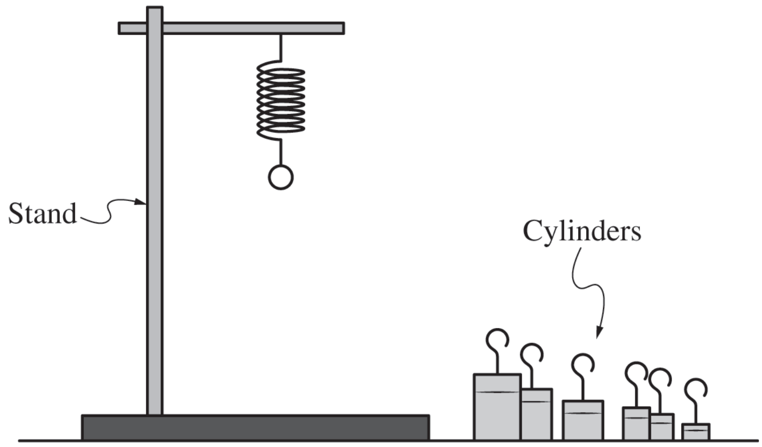


Figure 1

2. (12 points, suggested time 25 minutes)

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(a) Design an experimental procedure the student could use to determine the spring constant k of the spring.

In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.

In the space below the table, **describe** the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. If needed, you may include a simple diagram of the setup with your procedure.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
		Stopwatch
		Digital scale
Procedure (and diagram, if needed)		

(b)

i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis:____________________ Horizontal axis:____________________

ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

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Continue your response to **QUESTION 2** on this page.

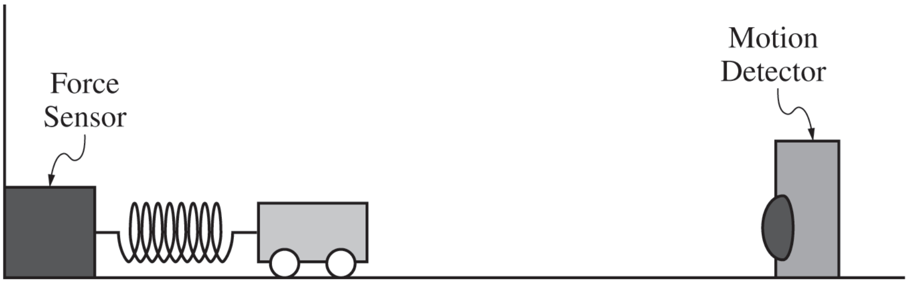
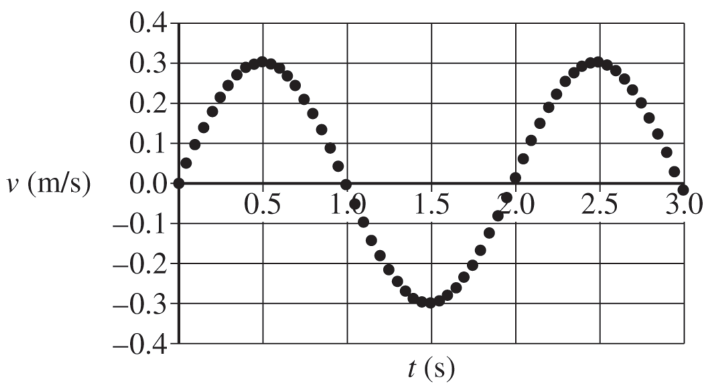
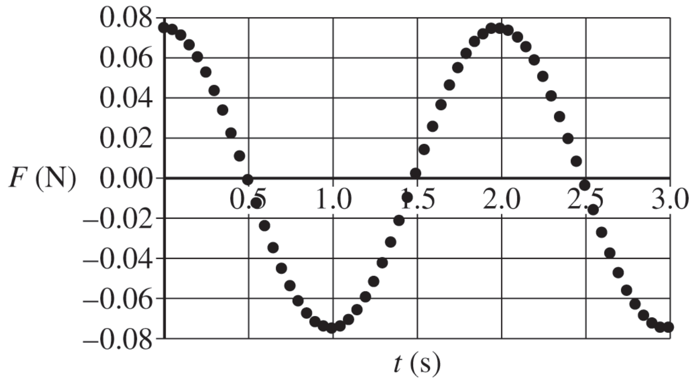


Figure 2

In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.





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Continue your response to **QUESTION 2** on this page.

(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5\text{ s}$ to $t = 2.0\text{ s}$. Show your steps and substitutions.

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5\text{ s}$ to $t = 2.5\text{ s}$. Briefly **explain** how you arrived at your estimation.

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

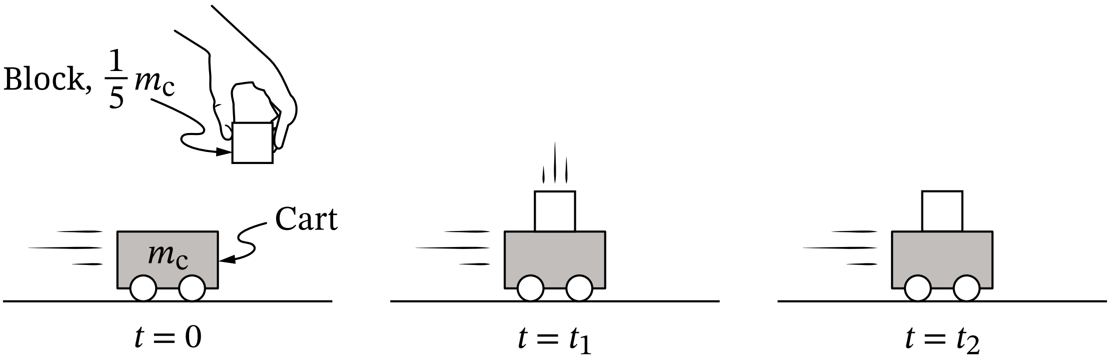
GO ON TO THE NEXT PAGE.

Question 1: Version J

1. A student has a cart of mass m_c and a block of mass $\frac{1}{5}m_c$, as shown in Figure 1.

- At time $t = 0$, the cart is moving to the right across a horizontal surface with constant speed v_c, and the student releases the block from rest.
- At $t = t_1$, the block collides with and sticks to the top of the cart. The block does not slide on the cart.
- At $t = t_2$, the block-cart system continues to move to the right with constant speed v_f.

Figure 1



A.

i. On the axes shown in Figure 2, **sketch** a graph of the magnitude p_x of the x-component of the momentum of the block-cart system as a function of time t from $t = 0$ until $t > t_2$.

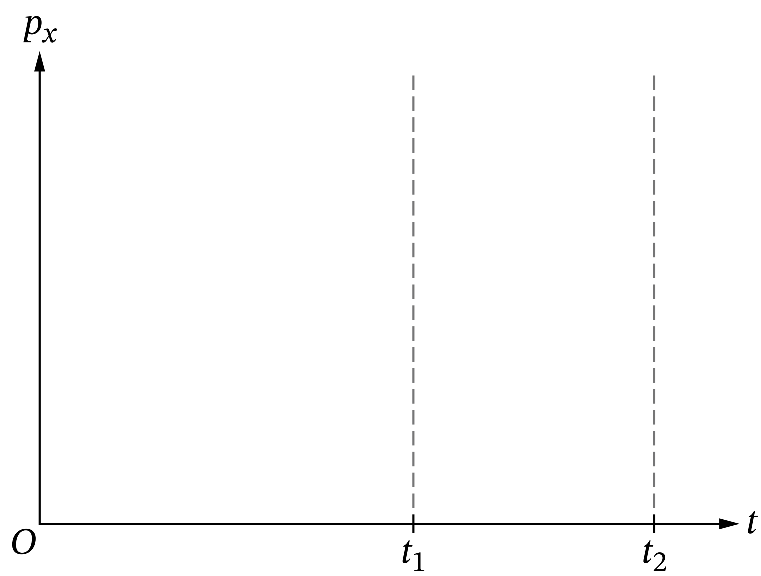


Figure 2

ii. **Derive** an expression for the speed v_f of the block-cart system after time $t = t_2$ in terms of m_c, v_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

iii. **Derive** an expression for the change in the kinetic energy ΔK in the block-cart system from $t = 0$ to $t = t_2$ in terms of m_c, v_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Consider the case where a new block is dropped and collides with the top of the cart. The new block slides along the cart during the collision but does not slide off the cart. The time interval from when the new block collides with the cart and moves together with the cart is Δt. During Δt there is a frictional force between the new block and the cart.

Indicate whether the x-component of the momentum of the new block-cart system increases, decreases, or remains constant during Δt.

______ Increases

______ Decreases

______ Remains constant

Justify your response.

4 Conservation of momentum and collisions – 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)		
conserved	守恒			
perfectly inelastic collision	非弹性碰撞			
elastic collision	弹性碰撞			
recoils	反冲			

Recall

In Part A you met momentum $p = mv$ and impulse. Now the big payoff:

- When two things push on each other, their pushes are equal and opposite (Newton's third law).
- So in a crash or an explosion, the **total** momentum does not change.
- This one idea solves collisions that would be hard to do with forces.

Each idea has a worked example before the Practice.

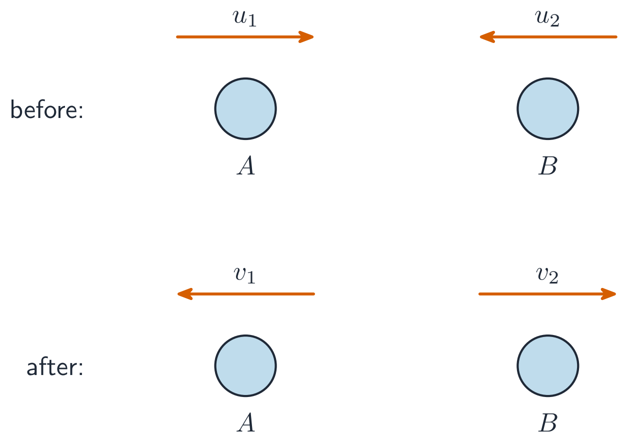
New ideas

1 Conservation of momentum

If no outside force acts on a system, its total momentum is **conserved** 守恒 – the total before equals the total after:

$$\sum p_{\text{before}} = \sum p_{\text{after}}.$$

The internal pushes come in equal-and-opposite pairs, so they cancel and cannot change the total.



2 Collisions that stick

In a **perfectly inelastic collision** 非弹性碰撞 the objects **stick together** and move off with one shared velocity.

Worked example. A 1000 kg car at 20 m/s hits a stationary 1500 kg car and they lock together. Momentum is conserved:

$$1000 \times 20 = (1000 + 1500)\,v \;\Rightarrow\; v = \frac{20000}{2500} = 8.0 \text{ m/s}.$$

3 Elastic and inelastic

Momentum is conserved in **every** collision, but kinetic energy is not:

- In an **elastic collision** 弹性碰撞, kinetic energy is also conserved (a clean bounce).
- In an **inelastic collision**, some kinetic energy becomes heat and deformation (a crash).

4 Recoil

When one part of a still system is pushed one way, the rest **recoils** 反冲 the other way so the total momentum stays zero.

Worked example. A 60 kg skater at rest throws a 2.0 kg ball at 8.0 m/s. Starting from zero total momentum: $0 = (60)v + (2.0)(8.0)$, so $v = -\dfrac{16}{60} = -0.27$ m/s – she slides back at 0.27 m/s. This is how rockets work.

Watch out: momentum is a **vector**. Give one direction a + sign and the opposite a − sign before you add – two equal speeds in opposite directions add to **zero** momentum, not double.

Practice

Try these in order. The methods are all above.

2.1 A 2.0 kg trolley at 3.0 m/s hits a stationary 1.0 kg trolley and they stick together. Find their common speed. [3]

2.2 State what is always conserved in a collision, and what is conserved only if the collision is elastic. [2]

2.3 A 50 kg student on frictionless ice throws a 1.0 kg ball at 6.0 m/s. Find the student's recoil speed. [3]

2.4 Two identical balls roll toward each other at the same speed and stick together. Explain why they stop. [2]

2.5 A 0.50 kg ball at 4.0 m/s collides head-on with a stationary 0.50 kg ball. After an **elastic** collision the first stops. State the second ball's speed and give your reason. [2]

2. (12 points, suggested time 25 minutes)

A new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

ii. What equipment would be used for the measurements, and how would that equipment be used?

iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

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Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

5 Rotational motion and torque – 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)		
angular displacement	角位移			
radians	弧度			
angular velocity	角速度			
Torque	力矩			
moment arm	力臂			

Recall

You already know spinning things – wheels, gears, a spinning top:

- A wheel turns through an angle; you have measured angles in degrees.
- A point on the edge of a big wheel moves faster than one near the middle.
- You have used a **seesaw** and a spanner: pushing farther from the pivot turns things more easily.

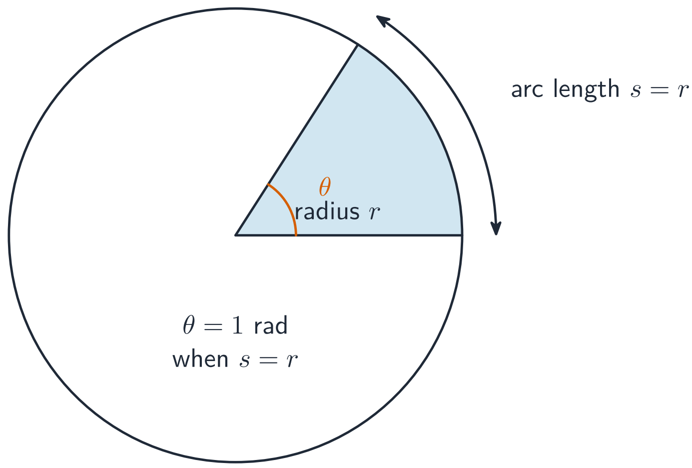
This sheet gives these ideas exact names and formulas. Each idea has a worked example.

New ideas

■ 1 Angular quantities

Rotation copies straight-line motion, with new names:

- **angular displacement** 角位移 θ – the angle turned, measured in **radians** 弧度 (one radian is the angle whose arc length equals the radius).
- **angular velocity** 角速度 $\omega = \dfrac{\Delta\theta}{\Delta t}$ – how fast it spins.



Worked example. A wheel turns 20 rad in 4.0 s, so $\omega = \dfrac{20}{4.0} = 5.0$ rad/s.

■ 2 Linking spin to straight-line speed

A point at distance r from the axis moves at speed

$$v = r\omega.$$

Points farther from the axis move faster.

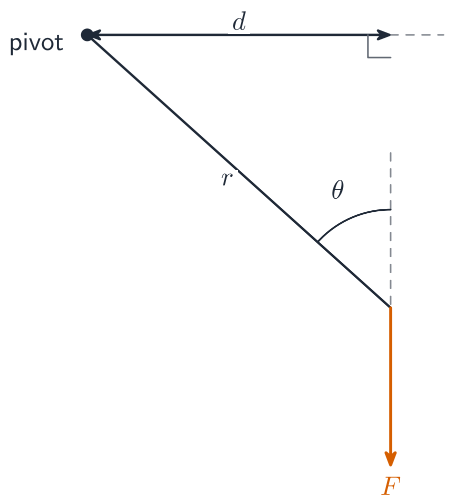
Worked example. A bicycle wheel of radius 0.35 m spins at 12 rad/s, so the rim (and the bike) moves at $v = r\omega = 0.35 \times 12 = 4.2$ m/s.

■ 3 Torque – the turning effect

Torque 力矩 (also called the moment) is how strongly a force turns something about a pivot:

$$\tau = F \times r_{\perp},$$

where $r_{\perp}$ is the **moment arm 力臂** – the perpendicular distance from the pivot to the line of the force.



Worked example. Pushing with 20 N at the end of a 0.30 m spanner, at right angles, gives $\tau = Fr = 20 \times 0.30 = 6.0$ N m.

Watch out: a force pointing straight **through** the pivot has zero moment arm, so it makes **no** torque. Push at a right angle, as far out as you can, for the biggest turning effect.

Practice

Try these in order. The methods are all above.

2.1 A wheel turns through 18 rad in 3.0 s. Find its angular velocity. [2]

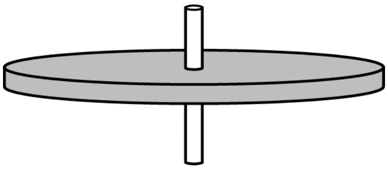
2.2 A point on a rim of radius 0.20 m has the wheel spinning at 10 rad/s. Find the speed of the point. [2]

2.3 A force of 15 N is applied at right angles 0.40 m from a pivot. Find the torque. [2]

2.4 Explain why a door handle is placed far from the hinges, not near them. [2]

2.5 Two points sit on a spinning disc, one at the rim and one halfway to the centre. State which moves faster and why. [2]

2.6 A spanner is 0.25 m long. You push with 30 N at right angles to it. Find the torque, then state what happens to the torque if you push at the same force but only halfway along. [3]



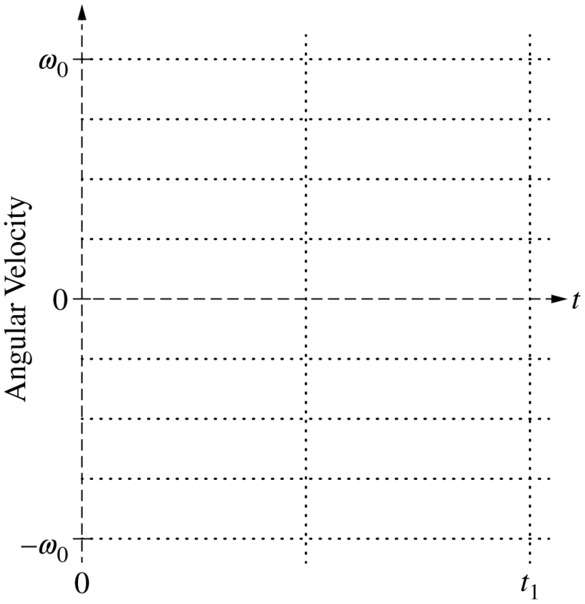
3. (12 points, suggested time 25 minutes)

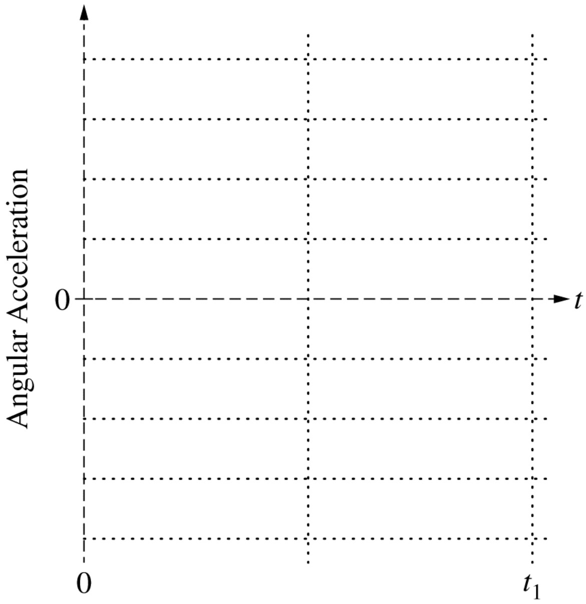
The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

(a) At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity ω_0. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.



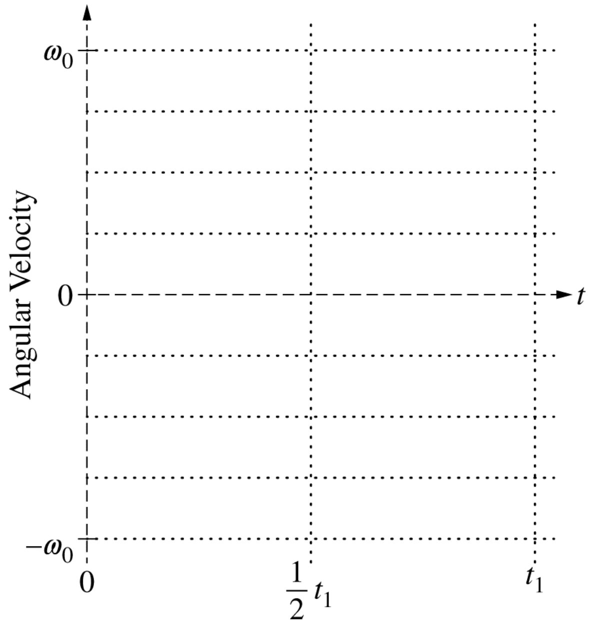


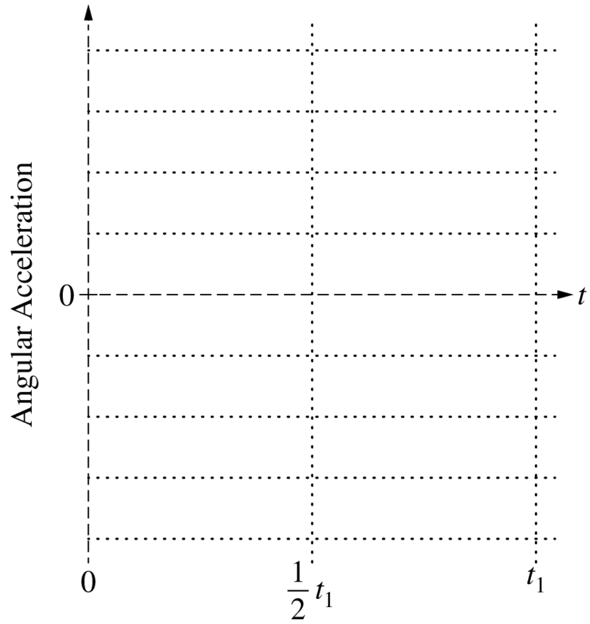
(b) The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

(c) In another experiment, the disk again has an initial positive angular velocity ω_0 at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.





(d) The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant (C_1 or C_2) with appropriate units.

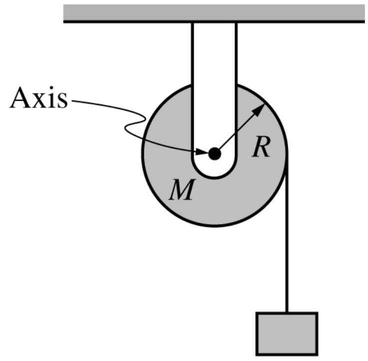
(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Which equation better mathematically models this experiment?

____ Equation (1) ____ Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.



. (7 points, suggested time 13 minutes)

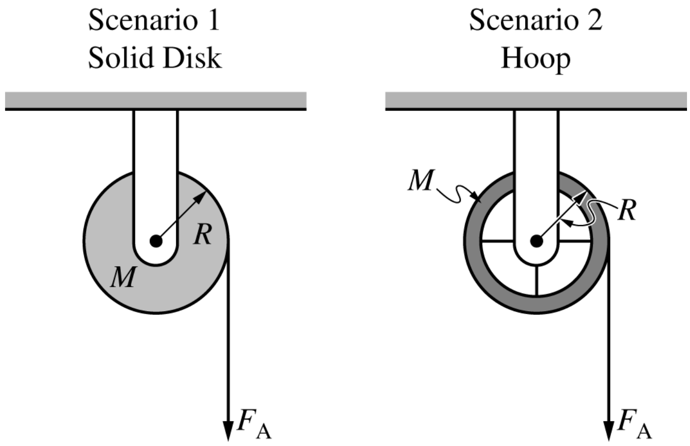
A block of unknown mass is attached to a long, lightweight string that is wrapped several turns around a pulley mounted on a horizontal axis through its center, as shown. The pulley is a uniform solid disk of mass M and radius R. The rotational inertia of the pulley is described by the equation $I = \frac{1}{2}MR^2$. The pulley can rotate about its center with negligible friction. The string does not slip on the pulley as the block falls.

When the block is released from rest and as the block travels toward the ground, the magnitude of the tension exerted on the block by the string is F_T.

(a) Determine an expression for the magnitude of the angular acceleration α_D of the disk as the block travels downward. Express your answer in terms of M, R, F_T, and physical constants as appropriate.

GO ON TO THE NEXT PAGE.

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

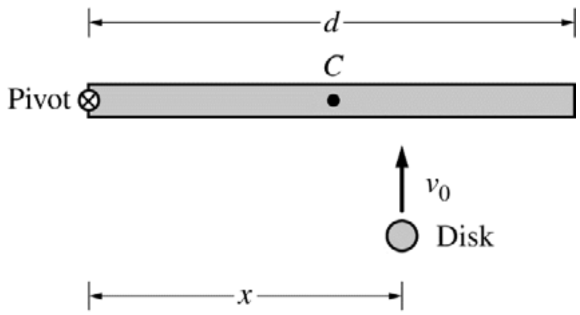


Scenarios 1 and 2 show two different pulleys. In Scenario 1, the pulley is the same solid disk referenced in part (a). In Scenario 2, the pulley is a hoop that has the same mass M and radius R as the disk. Each pulley has a lightweight string wrapped around it several turns and is mounted on a horizontal axle, as shown. Each pulley is free to rotate about its center with negligible friction.

In both scenarios, the pulleys begin at rest. Then both strings are pulled with the same constant force F_A for the same time interval Δt, causing the pulleys to rotate without the string slipping. After time interval Δt, the change in angular momentum of the disk is equal to the change in angular momentum of the hoop, but the change in rotational kinetic energy for the disk is greater than that of the hoop.

(b) Consider scenarios 1 and 2 at the end of time interval Δt. In a clear, coherent paragraph-length response that may also contain equations and drawings, explain why the change in angular momentum of both pulleys is the same but the change in rotational kinetic energy is greater for the disk.

GO ON TO THE NEXT PAGE.



Top View

3. (12 points, suggested time 25 minutes)

The left end of a rod of length d and rotational inertia I is attached to a frictionless horizontal surface by a frictionless pivot, as shown above. Point C marks the center (midpoint) of the rod. The rod is initially motionless but is free to rotate around the pivot. A student will slide a disk of mass m_{disk} toward the rod with velocity v_0 perpendicular to the rod, and the disk will stick to the rod a distance x from the pivot. The student wants the rod-disk system to end up with as much angular speed as possible.

(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C ?

____ To the left of C ____ At C ____ To the right of C

Briefly explain your reasoning without manipulating equations.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \dfrac{m_{disk}xv_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

____ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \dfrac{Ixv_0}{m_{disk}d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk}x^2$ and its angular momentum with respect to the pivot is $m_{disk}v_0x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

5 Rotational inertia, balance, and torque = I alpha – 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)		
Rotational inertia	转动惯量			
rotational equilibrium	转动平衡			

Recall

In Part A you met torque – the turning effect of a force. Now use it two ways:

- to **balance** things (a seesaw, a shelf), which you have done before;
- to find how fast something starts to spin, the rotational copy of $F = ma$.

Each idea has a worked example before the Practice.

New ideas

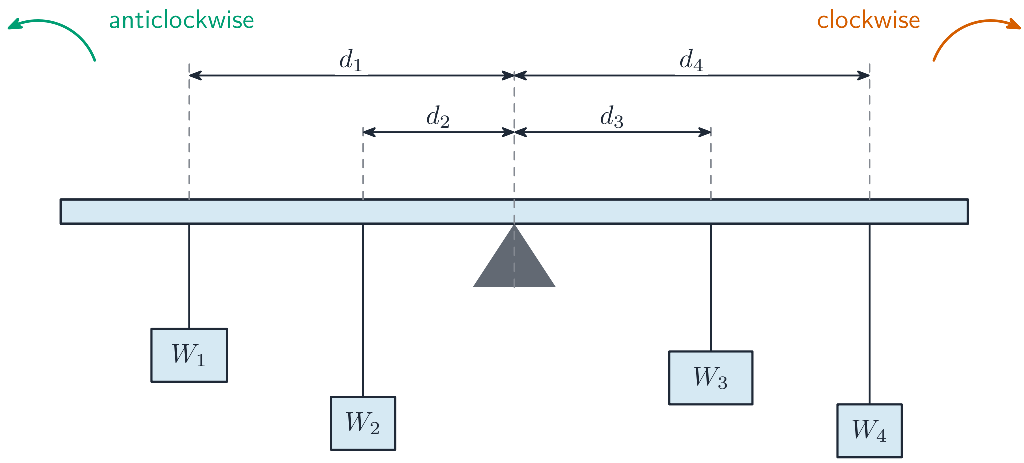
■ 1 Rotational inertia

Rotational inertia 转动惯量 (symbol I) measures how hard it is to change something's spin – the rotational version of mass. It depends on the mass **and how far** that mass sits from the axis: mass spread farther out makes I larger.

This is why a spinning skater speeds up when she pulls her arms **in** – she brings her mass closer to the axis, making I smaller.

■ 2 Rotational equilibrium

An object is in **rotational equilibrium** 转动平衡 when the total turning effect is zero – the clockwise torques balance the anticlockwise torques. Then it does not start to spin.



Worked example. A 30 kg child sits 2.0 m from the pivot of a seesaw. Where must a 40 kg child sit to balance it? Set the two torques equal (the g cancels):

$$30 \times 2.0 = 40 \times d \;\Rightarrow\; d = \frac{60}{40} = 1.5 \text{ m}.$$

The heavier child sits closer to the pivot.

■ 3 The rotational Newton's second law

Just as a net force gives linear acceleration, a **net torque** gives angular acceleration:

$$\sum \tau = I\alpha,$$

the exact twin of $\sum F = ma$ (with $\tau \leftrightarrow F$, $I \leftrightarrow m$, $\alpha \leftrightarrow a$).

Worked example. A net torque of 12 N m acts on a wheel with $I = 3.0$ kg m^2. Its angular acceleration is $\alpha = \frac{\tau}{I} = \frac{12}{3.0} = 4.0$ rad/s^2.

Watch out: the same mass can have different rotational inertia depending on where it sits – a ring is harder to spin than a solid disc of the same mass, because its mass is all at the edge.

Practice

Try these in order. The methods are all above.

2.1 State what two things the rotational inertia of an object depends on. [2]

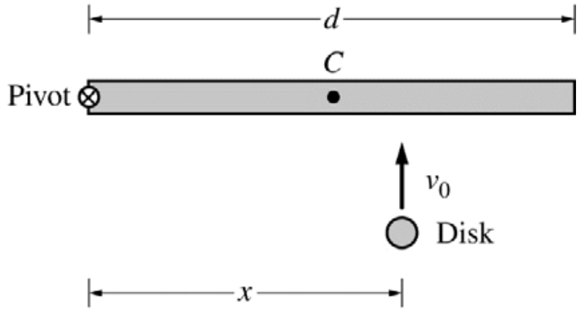
2.2 A 20 kg child sits 1.5 m from a seesaw pivot. A 25 kg child sits on the other side. How far from the pivot must the second child sit to balance? [3]

2.3 A net torque of 8.0 N m acts on a wheel of rotational inertia 2.0 kg m^2. Find the angular acceleration. [2]

2.4 Explain why a spinning ice skater speeds up when she pulls her arms in. [2]

2.5 A shelf is held by a bracket. State the condition on the torques for the shelf to stay balanced (not rotate). [1]

2.6 A wheel with $I = 5.0\ \mathrm{kg\ m^2}$ must reach $\alpha = 3.0\ \mathrm{rad/s^2}$. Find the net torque needed.[2]



Top View

3. (12 points, suggested time 25 minutes)

The left end of a rod of length d and rotational inertia I is attached to a frictionless horizontal surface by a frictionless pivot, as shown above. Point C marks the center (midpoint) of the rod. The rod is initially motionless but is free to rotate around the pivot. A student will slide a disk of mass m_{disk} toward the rod with velocity v_0 perpendicular to the rod, and the disk will stick to the rod a distance x from the pivot. The student wants the rod-disk system to end up with as much angular speed as possible.

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Briefly explain your reasoning without manipulating equations.

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For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{disk} x^2$ and its angular momentum with respect to the pivot is $m_{disk} v_0 x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

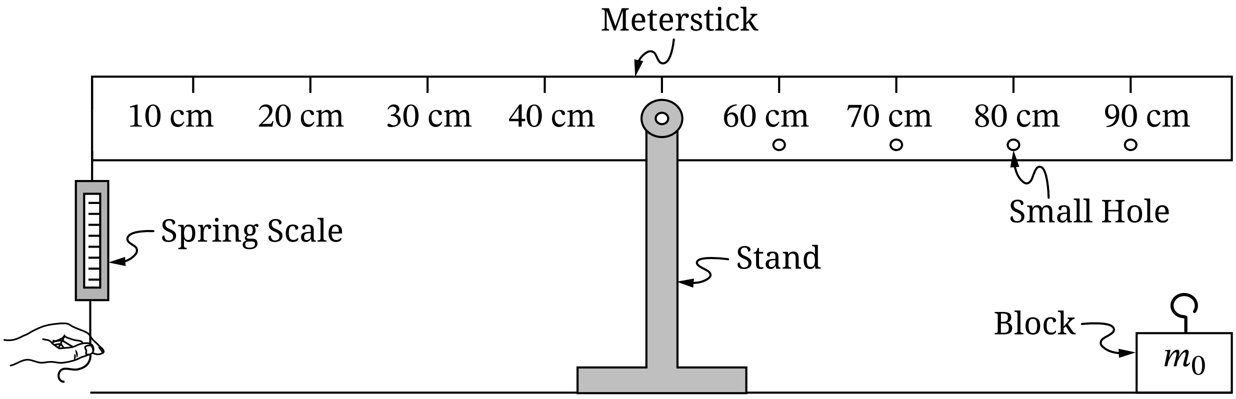
____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

Question 3: Version J

3. Students are investigating balancing systems using the following setup. The students have a spring scale of negligible mass that is fixed to one end of a uniform meterstick. The center of the meterstick is attached to a stand on which the meterstick can pivot. There is a hook of negligible mass fixed to the top of a block of mass m_0. The hook can be attached to the meterstick through one of the small holes in the meterstick, as shown in Figure 1. The students do not have a direct way to measure the mass of the block. The block cannot be attached to the spring scale.

Figure 1



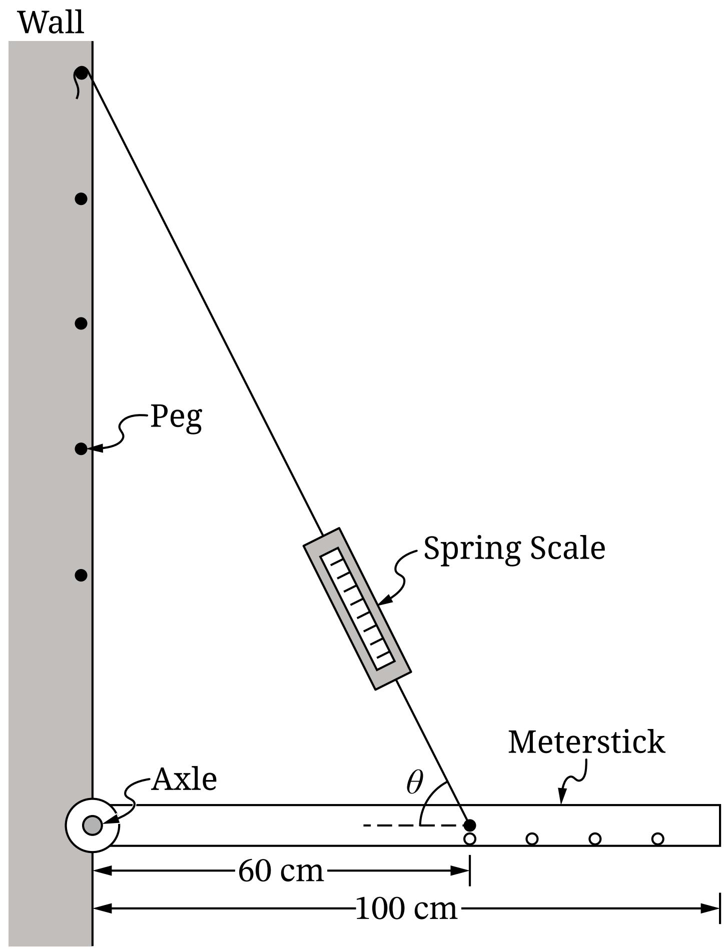
The students are asked to take measurements that will allow the students to create a linear graph whose slope could be used to determine the mass m_0 of the block.

A. Describe an experimental procedure to collect data that would allow the students to determine m_0. Include any steps necessary to reduce experimental uncertainty.

B. Describe how the data collected in part A could be graphed and how that graph would be analyzed to determine m_0.

The students have an identical meterstick of mass M that is now attached to an axle that is fixed to a wall. The meterstick is free to rotate with negligible friction about the axle. The meterstick is suspended horizontally by a string that is connected to a spring scale of negligible mass, as shown in Figure 2.

Figure 2



The angle θ that the string makes with the meterstick can be varied by attaching the string to one of the pegs located along the wall. The students use the spring scale to measure the tension F_T required to hold the meterstick horizontal. Table 1 shows the measured values of θ and F_T.

Table 1

θ (degrees)	F_T (N)
22	21
31	17
36	13
45	12
80	8

The students correctly determine that the relationship between F_T and θ is given by

$$F_T = \frac{5Mg}{6\sin\theta}.$$

The students create a graph with $\frac{1}{\sin\theta}$ plotted on the horizontal axis.

C.

i. **Indicate** what measured or calculated quantity could be plotted on the vertical axis to yield a linear graph whose slope can be used to calculate an experimental value for the mass M of the meterstick.

Vertical axis: ______ Horizontal axis: $\frac{1}{\sin\theta}$

ii. On the blank grid provided, create a graph of the quantities indicated in part C (i) that can be used to determine M.

- Use Table 2 to record the data points or calculated quantities that you will plot.
- Clearly **label** the vertical axis, including units as appropriate.
- **Plot** the points you recorded in Table 2.

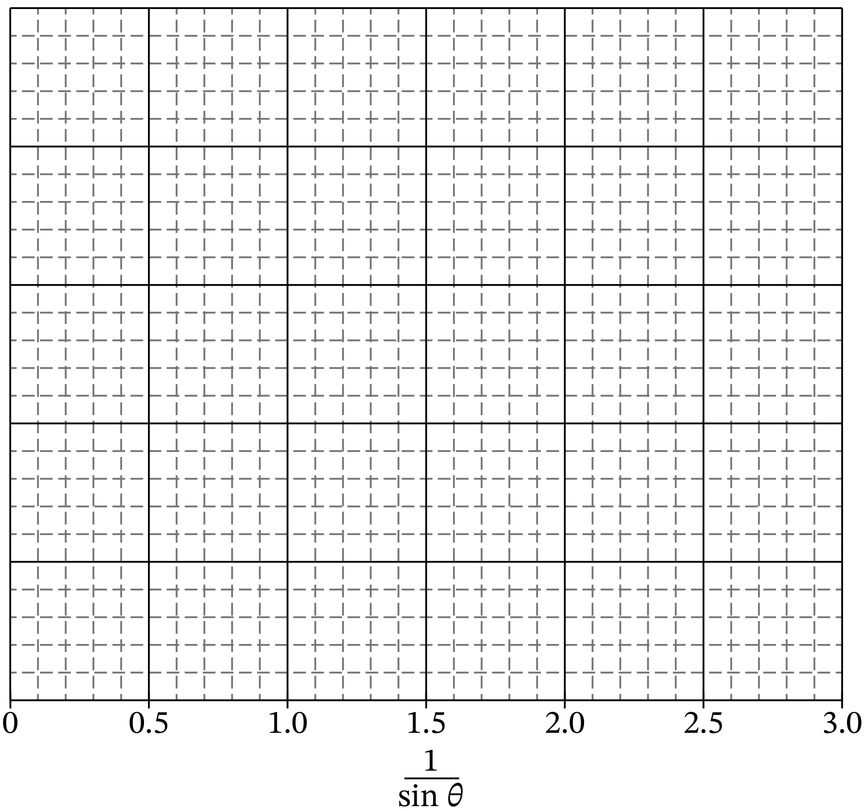


Figure 3

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

D. Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for the mass M of the meterstick.

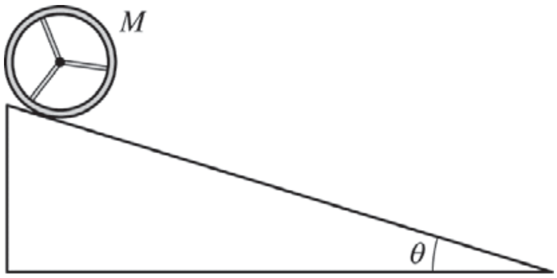
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

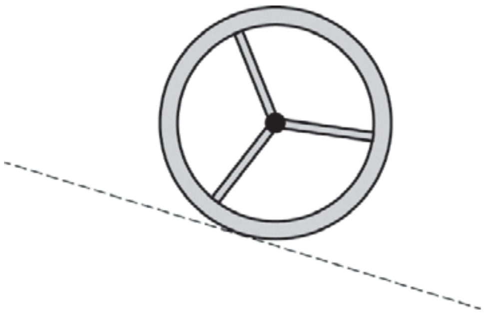


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ____ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

ii. Briefly explain your answer again, now reasoning in terms of energy.

6 Rotational energy and angular momentum – 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)		
rotational kinetic energy	转动动能			
Angular momentum	角动量			
conserved	守恒			

Recall

In the last topic you met angular velocity ω and rotational inertia I. Now spinning things get **energy** and **momentum**, just like moving things:

- A moving object has kinetic energy $\frac{1}{2}mv^2$ and momentum mv.
- A spinning object has rotational copies of both.
- A spinning skater who pulls her arms in speeds up – this sheet explains exactly why.

Each idea has a worked example before the Practice.

New ideas

■ 1 Rotational kinetic energy

A spinning object stores **rotational kinetic energy** 转动动能:

$$K_{\text{rot}} = \tfrac{1}{2}I\omega^2,$$

the twin of $\frac{1}{2}mv^2$. A rolling ball has **both**: $\frac{1}{2}mv^2$ from moving plus $\frac{1}{2}I\omega^2$ from spinning.

Worked example. A wheel with $I = 2.0$ kg m^2 spins at $\omega = 3.0$ rad/s: $K_{\text{rot}} = \frac{1}{2} \times 2.0 \times 3.0^2 = 9.0$ J.

■ 2 Work done by a torque

A torque turning through an angle does work: $W = \tau\,\Delta\theta$ (the twin of $W = Fd$).

Worked example. A motor gives a steady torque of 8.0 N m while a flywheel turns 10 rad: $W = \tau\,\Delta\theta = 8.0 \times 10 = 80$ J.

■ 3 Angular momentum

Angular momentum 角动量 is the rotational version of momentum:

$$L = I\omega.$$

■ 4 Conservation of angular momentum

If no outside torque acts, angular momentum is **conserved 守恒**:

$$I_1\omega_1 = I_2\omega_2.$$

So if I goes down, ω goes up to keep L the same.

Worked example. A skater spins at 2.0 rev/s with $I_1 = 4.0$ kg m^2. She pulls her arms in, dropping I to $I_2 = 1.6$ kg m^2: $\omega_2 = \dfrac{I_1}{I_2}\omega_1 = \dfrac{4.0}{1.6} \times 2.0 = 5.0$ rev/s.

Watch out: pulling the arms in raises **both** the spin rate and the kinetic energy – the extra energy comes from the work her muscles do pulling inward. Angular momentum stays the same; energy does not.

Practice

Try these in order. The methods are all above.

2.1 A flywheel with $I = 3.0$ kg m^2 spins at 4.0 rad/s. Find its rotational kinetic energy. [2]

2.2 A torque of 6.0 N m turns a wheel through 5.0 rad. Find the work done. [2]

2.3 Find the angular momentum of a disc with $I = 0.50$ kg m^2 spinning at 8.0 rad/s. [2]

2.4 A spinning student on a stool has $I_1 = 6.0$ kg m^2 at $\omega_1 = 1.0$ rad/s. He pulls weights in so $I_2 = 2.0$ kg m^2. Find his new angular velocity. [3]

2.5 State what stays the same and what changes when the student in 2.4 pulls the weights in. [2]

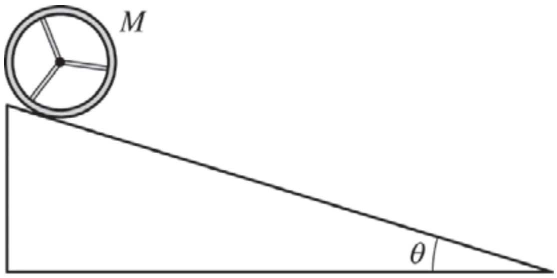
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

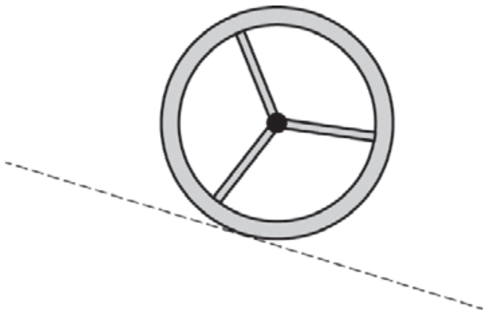


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ____ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

ii. Briefly explain your answer again, now reasoning in terms of energy.

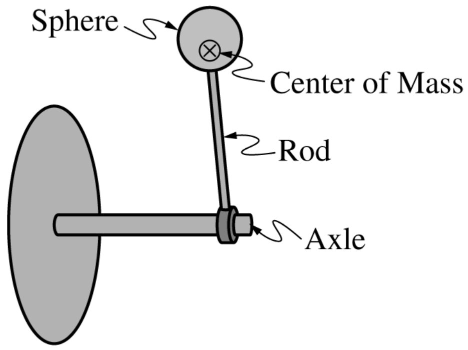


Figure 1

. (7 points, suggested time 13 minutes)

A rod with a sphere attached to the end is connected to a horizontal mounted axle and carefully balanced so that it rests in a position vertically upward from the axle. The center of mass of the rod-sphere system is indicated with a ⊗, as shown in Figure 1. The sphere is lightly tapped, and the rod-sphere system rotates clockwise with negligible friction about the axle due to the gravitational force.

A student takes a video of the rod rotating from the vertically upward position to the vertically downward position. Figure 2 shows five frames (still shots) that the student selected from the video.
Note: these frames are not equally spaced apart in time.

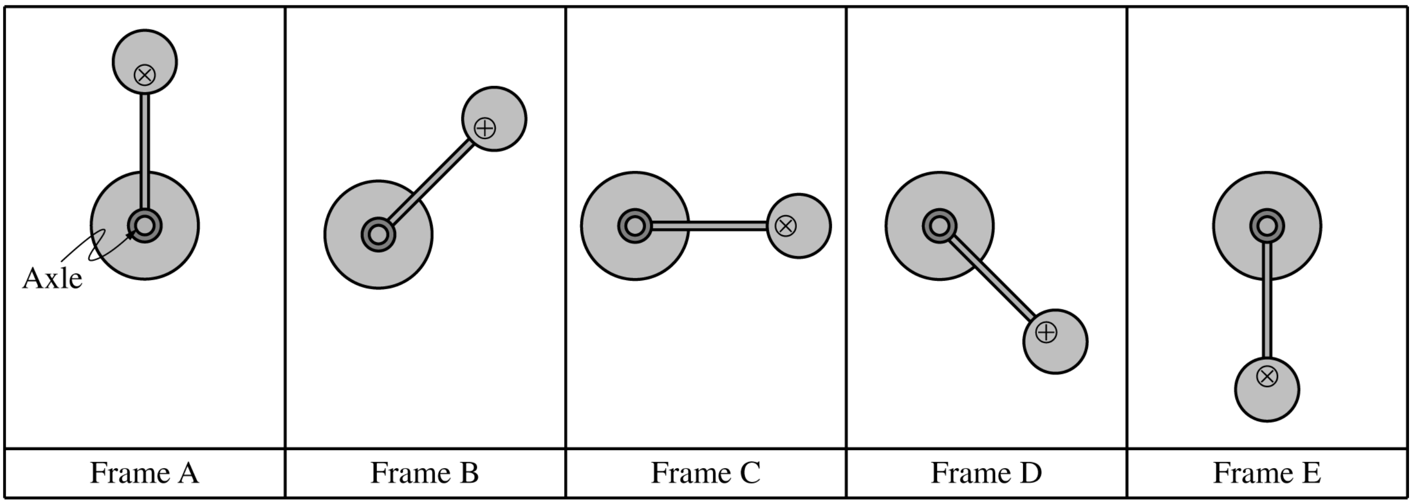


Figure 2

Continue your response to **QUESTION 5** on this page.

(a) Use the frames of the video shown in Figure 2 to answer the following questions.

i. In which frame is the angular acceleration of the rod-sphere system the greatest? Justify your answer.

ii. In which frame is the rotational kinetic energy of the rod-sphere system the greatest? Briefly justify your answer.

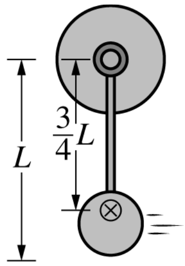


Figure 3

(b) The rod-sphere system has mass M and length L, and the center of mass is located a distance $\frac{3}{4}L$ from the axle, shown in Figure 3.

i. Derive an expression for the change in kinetic energy of the rod-sphere-Earth system from the moment shown in Frame A to the moment shown in Frame E. Express your answer in terms of M, L, and fundamental constants, as appropriate.

ii. Briefly explain why the rod and sphere gain kinetic energy, even if Earth is not included in the system.

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

6 Rolling and orbiting satellites – 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)		
rolls without slipping	纯滚动	______	______	______
satellite	卫星	______	______	______

Recall

In Part A you met rotational energy and angular momentum. Two everyday examples bring them together:

- A wheel that **rolls** is moving and spinning at the same time.
- A **satellite** stays in orbit because gravity keeps pulling it toward the planet.

Each idea has a worked example before the Practice.

New ideas

1 Rolling without slipping

When a wheel **rolls without slipping** 纯滚动, the point touching the ground is momentarily still, and the speed of the centre links to the spin:

$$v = r\omega.$$

Worked example. A wheel of radius 0.30 m rolls so its centre moves at 6.0 m/s. Its spin rate is $\omega = \frac{v}{r} = \frac{6.0}{0.30} = 20$ rad/s.

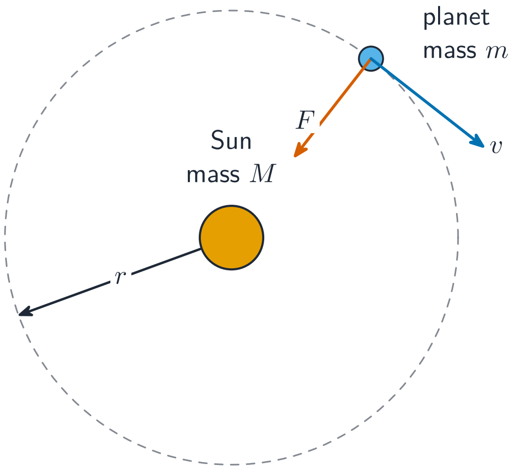
2 Rolling shares the energy

A rolling object splits its kinetic energy between **moving** ($\frac{1}{2}mv^2$) and **spinning** ($\frac{1}{2}I\omega^2$). Because some energy goes into spin, a ball rolling down a ramp speeds up **more slowly** than a block that slides down without friction.

3 Satellites and orbits

A **satellite** 卫星 in orbit is really in free fall: gravity provides exactly the **centripetal force** needed to bend its path into a circle. Setting gravity equal to the centripetal requirement gives the orbit speed

$$v = \sqrt{\frac{GM}{r}}.$$



Worked example. For a low orbit, $r = 6.4 \times 10^6$ m and $GM = 4.0 \times 10^{14}$ m^3/s^2: $v = \sqrt{\dfrac{4.0 \times 10^{14}}{6.4 \times 10^6}} \approx 7.9 \times 10^3$ m/s, about 7.9 km/s.

4 Bigger orbit, slower speed

Because $v = \sqrt{GM/r}$, a satellite farther out (*larger* r) moves **slower**. The satellite's own mass cancels, so all satellites in the same orbit move at the same speed.

Watch out: a satellite is not "beyond gravity." Gravity is exactly what holds it in orbit – it is falling toward the planet all the time, but moving sideways fast enough to keep missing it.

Practice

Try these in order. The methods are all above.

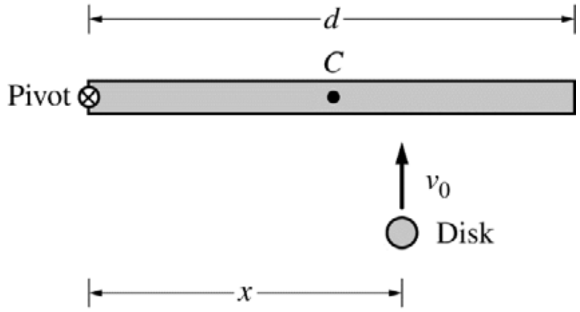
2.1 A wheel of radius 0.25 m rolls without slipping; its centre moves at 5.0 m/s. Find its angular velocity. [2]

2.2 Explain why a ball rolling down a slope accelerates more slowly than a block sliding down the same frictionless slope. [2]

2.3 What force provides the centripetal force that keeps a satellite in orbit? [1]

2.4 Two satellites orbit the same planet, one close and one far. State which moves faster, and why. [2]

2.5 A wheel of radius 0.40 m spins at $\omega = 15$ rad/s while rolling. Find the speed of its centre. [2]



Top View

3. (12 points, suggested time 25 minutes)

The left end of a rod of length d and rotational inertia I is attached to a frictionless horizontal surface by a frictionless pivot, as shown above. Point C marks the center (midpoint) of the rod. The rod is initially motionless but is free to rotate around the pivot. A student will slide a disk of mass m_{disk} toward the rod with velocity v_0 perpendicular to the rod, and the disk will stick to the rod a distance x from the pivot. The student wants the rod-disk system to end up with as much angular speed as possible.

(a) Suppose the rod is much more massive than the disk. To give the rod as much angular speed as possible, should the student make the disk hit the rod to the left of point C, at point C, or to the right of point C ?

____ To the left of C ____ At C ____ To the right of C

Briefly explain your reasoning without manipulating equations.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \dfrac{m_{\text{disk}} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

____ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \dfrac{I x v_0}{m_{\text{disk}} d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

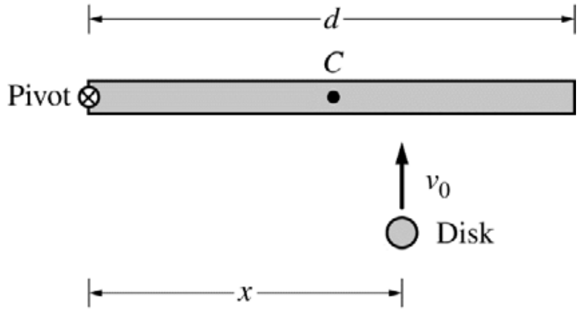
For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{\text{disk}} x^2$ and its angular momentum with respect to the pivot is $m_{\text{disk}} v_0 x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.



Top View

3. (12 points, suggested time 25 minutes)

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____ To the left of C ____ At C ____ To the right of C

Briefly explain your reasoning without manipulating equations.

(b) On the Internet, a student finds the following equation for the postcollision angular speed ω of the rod in this situation: $\omega = \dfrac{m_{\text{disk}} x v_0}{I}$. Regardless of whether this equation for angular speed is correct, does it agree with your qualitative reasoning in part (a) ? In other words, does this equation for ω have the expected dependence as reasoned in part (a) ?

____ Yes ____ No

Briefly explain your reasoning without deriving an equation for ω.

(c) Another student deriving an equation for the postcollision angular speed ω of the rod makes a mistake and comes up with $\omega = \dfrac{I x v_0}{m_{\text{disk}} d^4}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

For parts (d) and (e), do NOT assume that the rod is much more massive than the disk.

(d) Immediately before colliding with the rod, the disk's rotational inertia about the pivot is $m_{\text{disk}} x^2$ and its angular momentum with respect to the pivot is $m_{\text{disk}} v_0 x$. Derive an equation for the postcollision angular speed ω of the rod. Express your answer in terms of d, m_{disk}, I, x, v_0, and physical constants, as appropriate.

(e) Consider the collision for which your equation in part (d) was derived, except now suppose the disk bounces backward off the rod instead of sticking to the rod. Is the postcollision angular speed of the rod when the disk bounces off it greater than, less than, or equal to the postcollision angular speed of the rod when the disk sticks to it?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

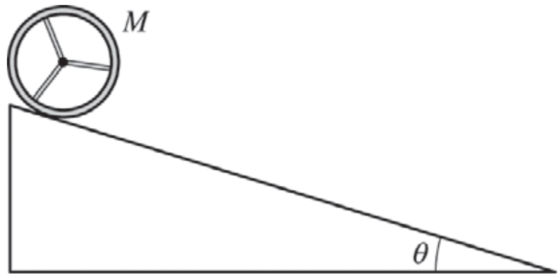
PHYSICS 1

Section II

5 Questions

Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 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.

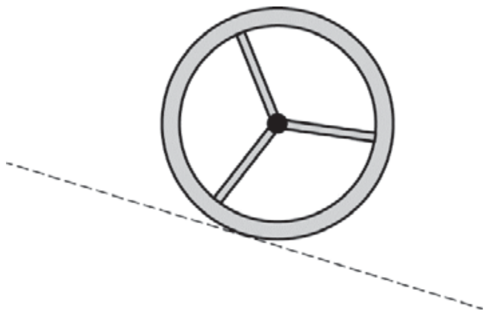


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ____ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

ii. Briefly explain your answer again, now reasoning in terms of energy.

7 Simple harmonic motion, period, and frequency – 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)		
Simple harmonic motion	简谐运动			
oscillation	振动			
restoring force	回复力			
period	周期			
frequency	频率			

Recall

You have watched things swing and bounce back and forth:

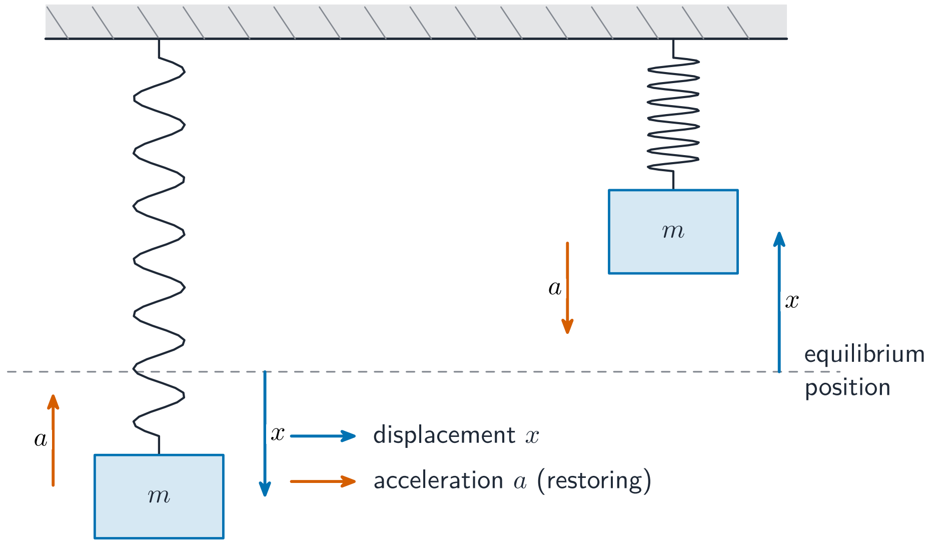
- A pendulum swings side to side; a mass on a spring bounces up and down.
- The motion repeats over and over, each cycle taking about the same time.
- A stiffer spring bounces faster; a longer pendulum swings slower.

This sheet gives the repeating motion a name – simple harmonic motion – and simple formulas. Each idea has a worked example.

New ideas

1 Simple harmonic motion

Simple harmonic motion 简谐运动 (SHM) is a back-and-forth **oscillation** 振动 caused by a **restoring force** 回复力 that always pulls the object back toward the middle, and grows with the distance from the middle ($F = -kx$).



A mass on a spring, and a pendulum swinging through **small** angles, are the standard examples.

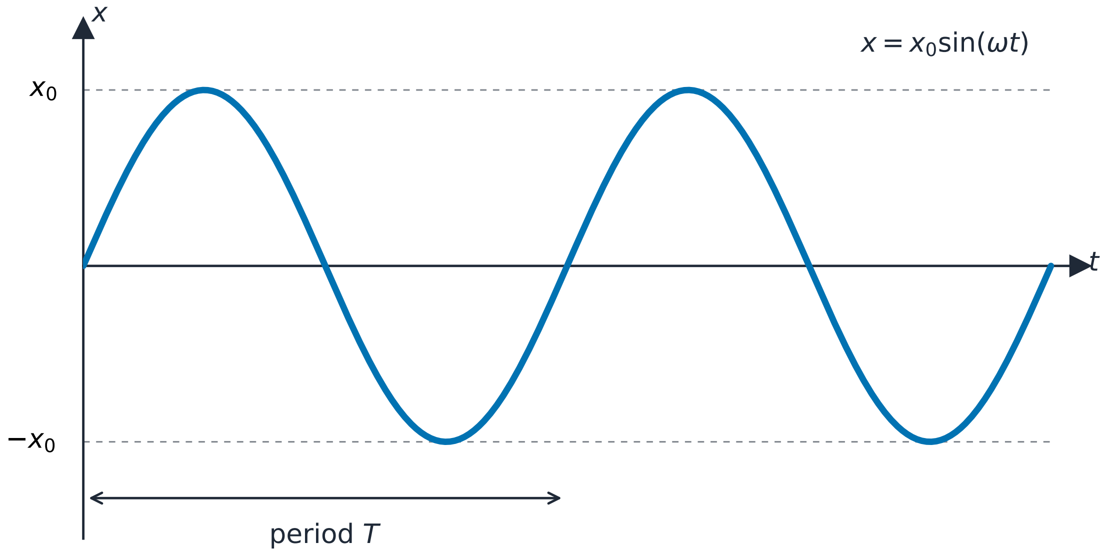
2 Period and frequency

- The **period** 周期 T is the time for one full cycle.
- The **frequency** 频率 $f = \dfrac{1}{T}$ is the number of cycles per second (in hertz, Hz).

3 The period formulas

For SHM the period depends only on the system, **not** on how big the swing is:

$$T_{\text{spring}} = 2\pi\sqrt{\frac{m}{k}}, \qquad T_{\text{pendulum}} = 2\pi\sqrt{\frac{L}{g}}.$$



Worked example. A 0.25 kg mass hangs on a spring of stiffness $k = 100$ N/m:

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.25}{100}} = 0.31 \text{ s}, \qquad f = \frac{1}{T} = 3.2 \text{ Hz}.$$

Watch out: the period does **not** depend on the amplitude – a wide swing and a narrow swing take the same time. That is exactly what makes a pendulum a good clock.

Practice

Try these in order. The methods are all above.

2.1 A pendulum completes one full swing (there and back) in 2.0 s. State its period and find its frequency. [2]

2.2 Name the two conditions a force must meet to cause simple harmonic motion. [2]

2.3 A 0.40 kg mass sits on a spring of stiffness $k = 160$ N/m. Find the period of its oscillation. [3]

2.4 State what happens to a spring's period if the mass is increased. [1]

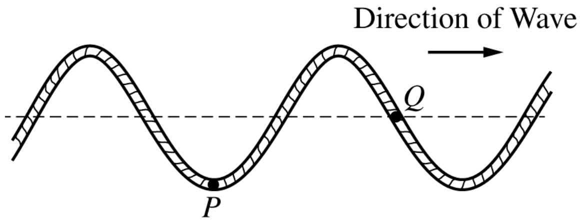
2.5 A pendulum has period 1.0 s. A student makes the swing wider (larger amplitude). State the effect on the period, and explain. [2]

4. (7 points, suggested time 13 minutes)

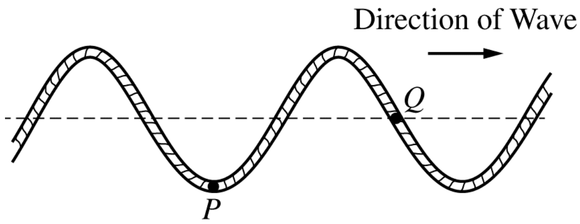
A transverse wave travels to the right along a string.

(a) Two dots have been painted on the string. In the diagrams below, those dots are labeled P and Q.

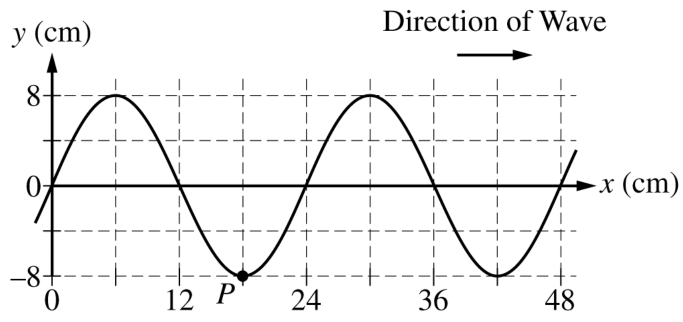
i. The figure below shows the string at an instant in time. At the instant shown, dot P has maximum displacement and dot Q has zero displacement from equilibrium. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous velocity of that dot. If either dot has zero velocity, write "$v = 0$" next to the dot.



ii. The figure below shows the string at the same instant as shown in part (a)i. At each of the dots P and Q, draw an arrow indicating the direction of the instantaneous acceleration of that dot. If either dot has zero acceleration, write "$a = 0$" next to the dot.



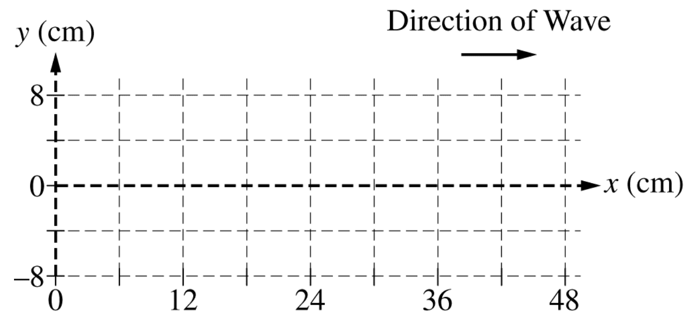
The figure below represents the string at time $t = 0$, the same instant as shown in part (a) when dot P is at its maximum displacement from equilibrium. For simplicity, dot Q is not shown.



(b)

i. On the grid below, draw the string at a later time $t = T/4$, where T is the period of the wave.

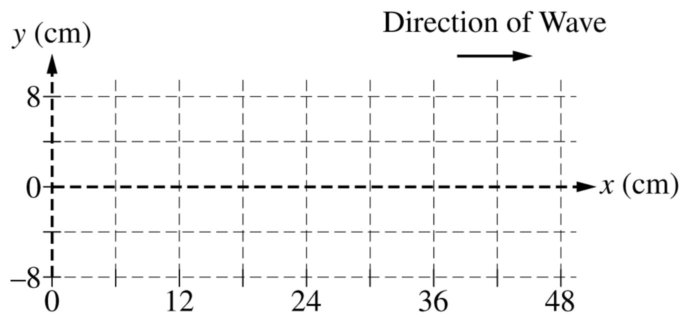
Note: Do any scratch (practice) work on the grid at the bottom of the page. Only the sketch made on the grid immediately below will be graded.

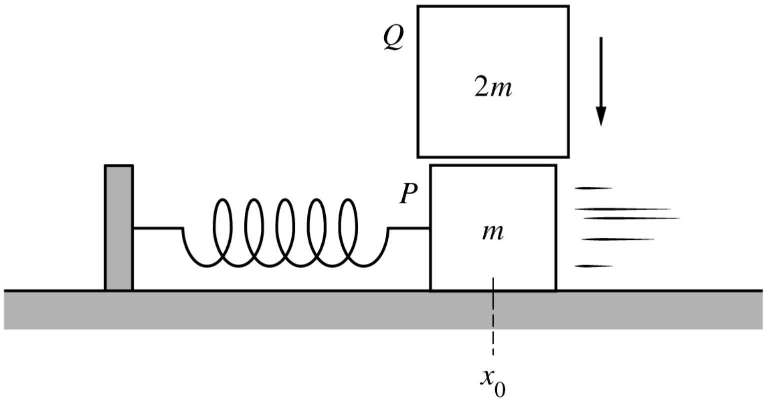


ii. On your drawing above, draw a dot to indicate the position of dot P on the string at time $t = T/4$ and clearly label the dot with the letter P.

(c) Now consider the wave at time $t = T$. Determine the distance traveled (not the displacement) by dot P between times $t = 0$ and $t = T$.

The grid below is provided for scratch work only. Sketches made below will not be graded.

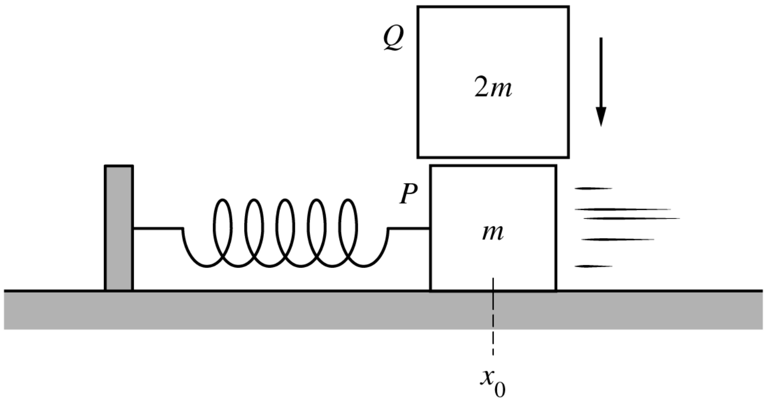




5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) Determine the numerical value of the ratio T_{PQ}/T_P.



(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

____ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

STOP

END OF EXAM

7 The energy of oscillations – 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)
equilibrium position	平衡位置	____________ ____________ ____________
amplitude	振幅	____________ ____________ ____________

Recall

In Part A you met simple harmonic motion and its period. Now follow the **energy** and **speed** through one cycle:

- At the far ends of a swing the object stops for an instant, then turns back.
- At the middle it is moving fastest.
- The energy keeps swapping between two forms while the total stays fixed.

Each idea has a worked example before the Practice.

New ideas

■ 1 Speed and acceleration through the cycle

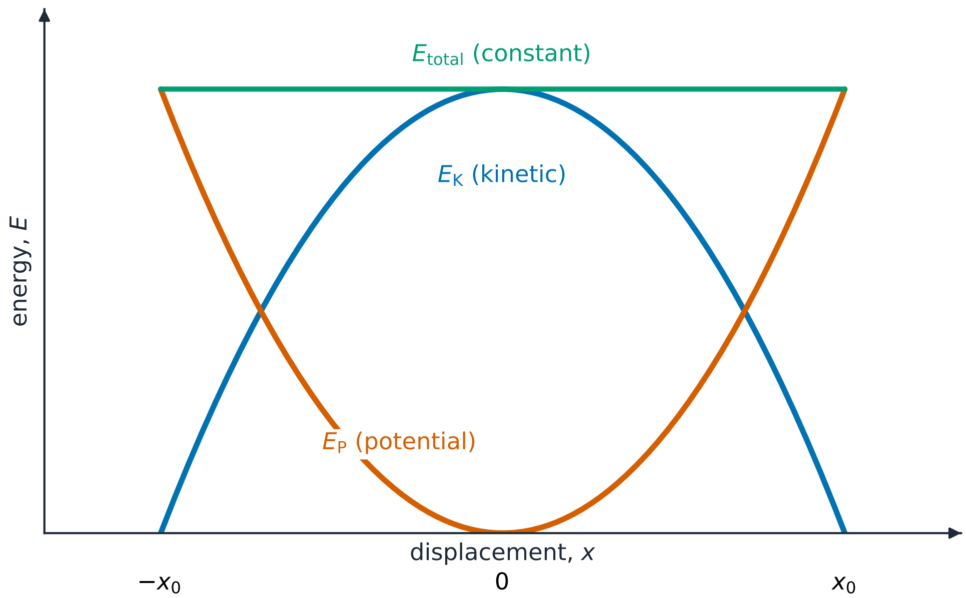
As the object oscillates about its **equilibrium position** 平衡位置 (the middle):

- At the **ends** (maximum displacement, called the **amplitude** 振幅 A): the speed is **zero** and the acceleration is largest.
- At the **middle** ($x = 0$): the acceleration is zero and the **speed is largest**.

■ 2 Energy swaps between two forms

The energy slides back and forth between kinetic and elastic potential, while the **total** stays constant (no friction):

$$E = \frac{1}{2}kA^2.$$



- At the ends: all **potential** (stretched spring, not moving).
- At the middle: all **kinetic** (moving fastest, spring relaxed).

Worked example. A 0.50 kg mass on a spring ($k = 200$ N/m) has amplitude $A = 0.10$ m. All the energy is kinetic at the middle, so $\frac{1}{2}kA^2 = \frac{1}{2}mv_{\max}^2$, giving $v_{\max} = A\sqrt{\frac{k}{m}} = 0.10 \times \sqrt{\frac{200}{0.50}} = 2.0$ m/s.

■ 3 Amplitude and energy

Because $E = \frac{1}{2}kA^2$, the energy depends on the **square** of the amplitude – double the amplitude and the energy becomes **four times** larger.

Watch out: the fastest point is the **middle**, not the ends. At the ends the object is momentarily at rest, even though the force on it is largest there.

Practice

Try these in order. The methods are all above.

2.1 State where in its swing an oscillating mass has (a) maximum speed, (b) zero speed.[2]

2.2 At which point of the motion is all the energy kinetic? [1]

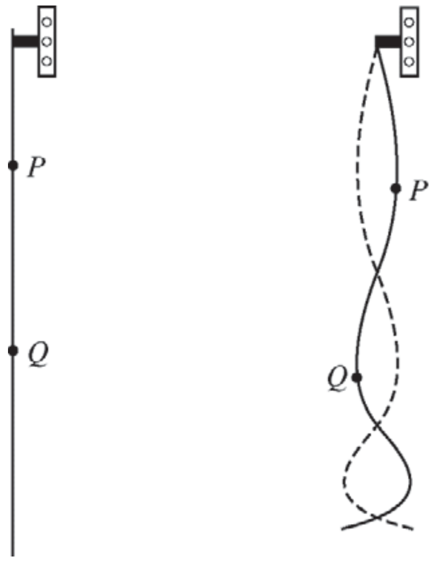
2.3 A spring ($k = 300$ N/m) oscillates with amplitude $A = 0.20$ m. Find the total energy

$E = \frac{1}{2}kA^2$. [2]

2.4 A 0.20 kg mass on a spring ($k = 80$ N/m) has amplitude 0.15 m. Find its maximum speed. [3]

2.5 The amplitude of an oscillation is doubled. State the factor by which the total energy changes. [1]

2.6 Explain why the acceleration is largest at the ends of the swing, even though the speed there is zero. [2]



5. (7 points, suggested time 13 minutes)

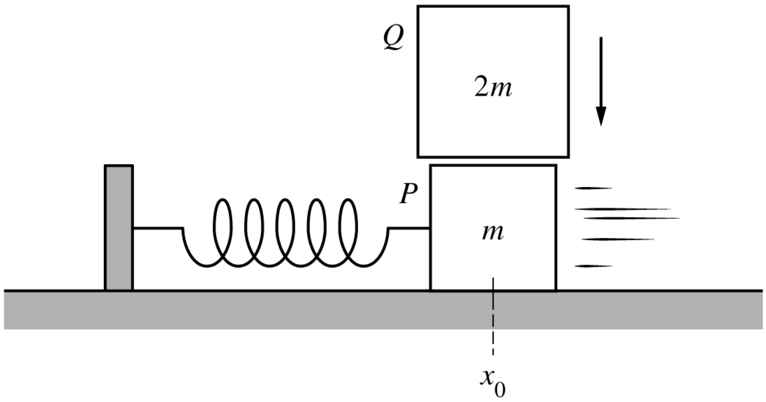
The figure above on the left shows a uniformly thick rope hanging vertically from an oscillator that is turned off. When the oscillator is on and set at a certain frequency, the rope forms the standing wave shown above on the right. *P* and *Q* are two points on the rope.

(a) The tension at point *P* is greater than the tension at point *Q*. Briefly explain why.

(b) A student hypothesizes that increasing the tension in a rope increases the speed at which waves travel along the rope. In a clear, coherent paragraph-length response that may also contain figures and/or equations, explain why the standing wave shown above supports the student's hypothesis.

STOP

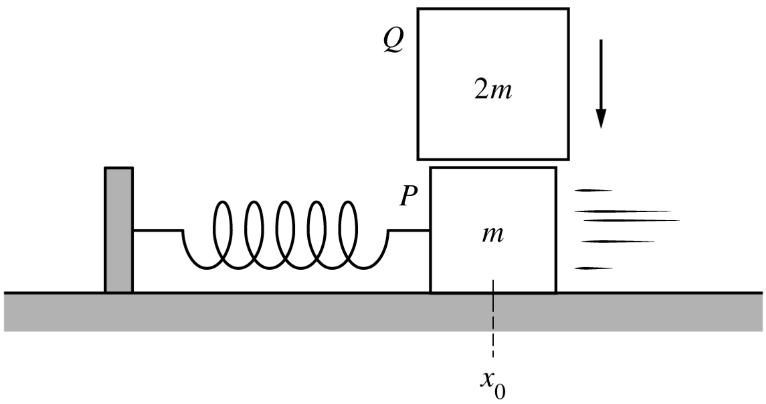
END OF EXAM



5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k. The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0. A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P, and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ}.

(a) Determine the numerical value of the ratio T_{PQ}/T_P.



(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

____ $A_{PQ} < A_P$ ____ $A_{PQ} = A_P$ ____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

STOP

END OF EXAM

8 Density and pressure – 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)		
fluid	流体			
Density	密度			
Pressure	压强			
depth	深度			

Recall

You already know a lot about liquids and gases:

- Some things float on water and some sink.
- Deep water presses harder – your ears feel it at the bottom of a pool.
- Air and water can both flow. We call anything that flows a **fluid**.

This sheet turns these everyday facts into exact formulas. Each idea has a worked example.

New ideas

1 Fluids and density

A **fluid** 流体 is a liquid or gas – its particles can move past each other, so it flows. **Density** 密度 is how much mass is packed into each unit of volume:

$$\rho = \frac{m}{V}.$$

Something less dense than the fluid around it floats; something denser sinks.

Worked example. A 2.0 kg block has volume 0.0025 m^3, so $\rho = \frac{m}{V} = \frac{2.0}{0.0025} =$

800 kg/m^3 – less than water (1000), so it floats.

2 Pressure

Pressure 压强 is force spread over an area, measured in pascals (Pa):

$$P = \frac{F}{A}.$$

The same force on a smaller area gives a bigger pressure (why a sharp knife cuts).

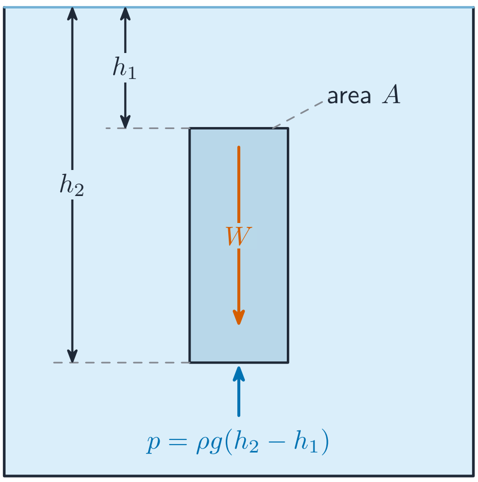
Worked example. A force of 50 N on an area of 0.010 m^2 gives $P = \frac{F}{A} = \frac{50}{0.010} =$ 5000 Pa.

3 Pressure and depth

In a still fluid, pressure grows with **depth** 深度, because of the weight of fluid above:

$$P = P_0 + \rho g h,$$

where P_0 is the pressure at the surface and h is the depth.



Worked example. At 10 m deep in water ($\rho = 1000$ kg/m^3, $P_0 = 1.0 \times 10^5$ Pa): $P = P_0 + \rho g h = 1.0 \times 10^5 + 1000 \times 9.8 \times 10 = 1.98 \times 10^5$ Pa.

Watch out: the pressure at a depth depends only on the **depth**, not on the shape or width of the container. A thin tube and a wide lake have the same pressure at the same depth.

Practice

Try these in order. The methods are all above.

2.1 A 3.0 kg object has a volume of 0.0015 m^3. Find its density. [2]

2.2 A force of 80 N acts on an area of 0.020 m^2. Find the pressure. [2]

2.3 An object has density 1200 kg/m^3. State whether it floats or sinks in water (1000 kg/m^3), and why. [2]

2.4 Find the extra pressure ($\rho g h$) at a depth of 5.0 m in water ($\rho = 1000$ kg/m^3, $g = 9.8$ m/s^2). [2]

2.5 Explain why a diver feels the same pressure at a given depth whether in a narrow well or a wide sea. [2]

2. (12 points, suggested time 25 minutes)

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.

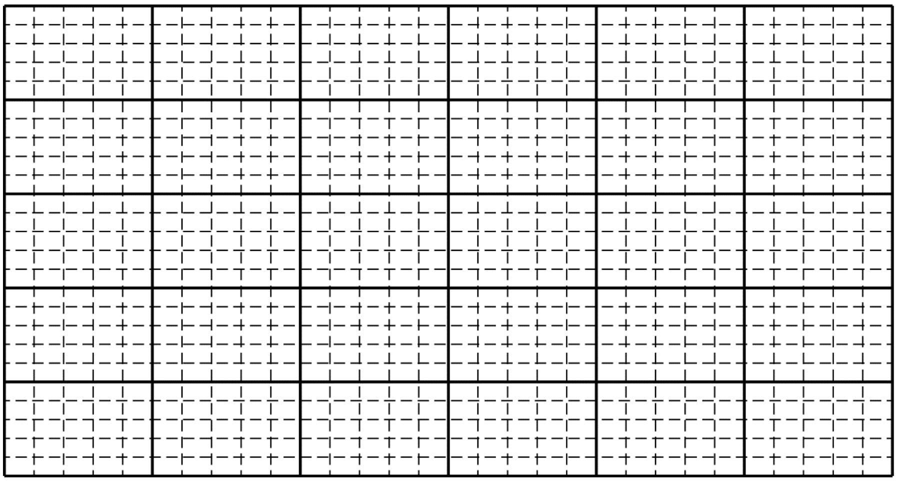
Dough Cylinder	A (m^2)	ℓ (m)	ΔV (V)	R (Ω)		
1	0.00049	0.030	1.02	23.6		
2	0.00049	0.050	2.34	31.5		
3	0.00053	0.080	3.58	61.2		
4	0.00057	0.150	6.21	105		

(a) The students want to determine the resistivity of the dough cylinders.

i. Indicate below which quantities could be graphed to determine a value for the resistivity of the dough cylinders. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

Vertical Axis: ________________________ Horizontal Axis: ________________________

ii. On the grid below, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.



iii. Use the above graph to estimate a value for the resistivity of the dough cylinders.

(b) Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?

____ Yes ____ No

Briefly justify your reasoning.

(c) Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of the experimental setup. Assume equipment usually found in a school physics laboratory is available.

(12 points, suggested time 25 minutes)

A group of students is investigating how the thickness of a plastic rod affects the maximum force F_{max} with which the rod can be pulled without breaking. Two students are discussing models to represent how F_{max} depends on rod thickness.
Student A claims that F_{max} is directly proportional to the radius of the rod.
Student B claims that F_{max} is directly proportional to the cross-sectional area of the rod—the area of the base of the cylinder, shaded gray in the figure above.

(a) The students have a collection of many rods of the same material. The rods are all the same length but come in a range of six different thicknesses. Design an experimental procedure to determine which student's model, if either, correctly represents how F_{max} depends on rod thickness.

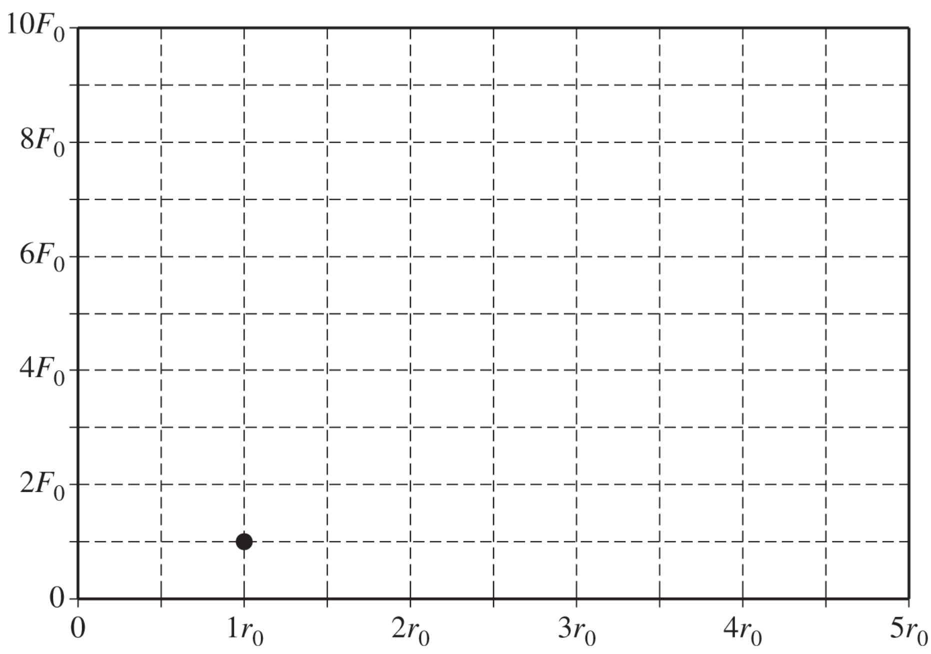
In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

GO ON TO THE NEXT PAGE.

Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

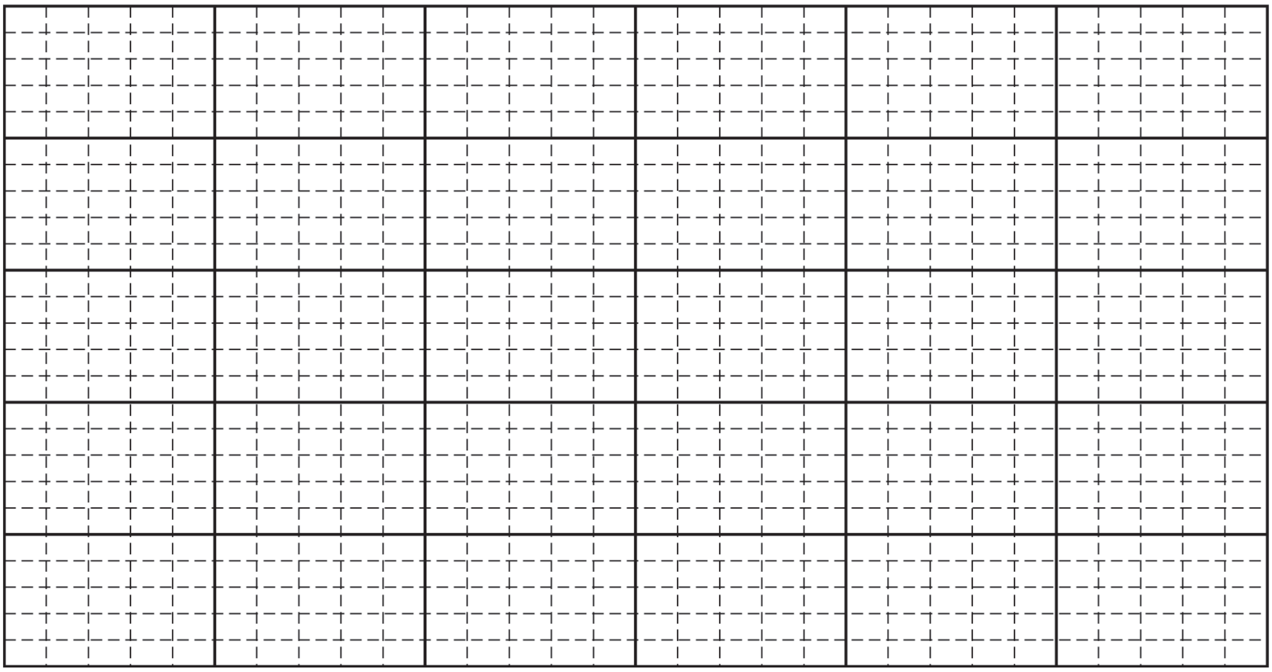
(b) For a rod of radius r_0, it is determined that F_{max} is F_0, as indicated by the dot on the grid below. On the grid, draw and label graphs corresponding to the two students' models of the dependence of F_{max} on rod radius. Clearly label each graph "A" or "B," corresponding to the appropriate model.



The table below shows results of measurements taken by another group of students for rods of different thicknesses.

Rod radius (mm)	0.5	1.0	1.5	2.0	2.5
F_{max} (N)	40	120	320	520	900

(c) On the grid below, plot the data points from the table. Clearly scale and label all axes, including units. Draw either a straight line or a curve that best represents the data.



(d) Which student's model is more closely represented by the evidence shown in the graph you drew in part (c) ?

____ Student A's model: F_{max} is directly proportional to the radius of the rod.

____ Student B's model: F_{max} is directly proportional to the cross-sectional area of the rod.

Explain your reasoning.

GO ON TO THE NEXT PAGE.

8 Buoyancy and flowing fluids – 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)		
buoyant force	浮力			
Archimedes' principle	阿基米德原理			
continuity	连续性			
Bernoulli's	伯努利			

Recall

In Part A you met density and pressure. Now two more fluid ideas you have already half-noticed:

- A ball pushed underwater pops back up – water pushes objects up.
- Squeeze a hose and the water shoots out faster.

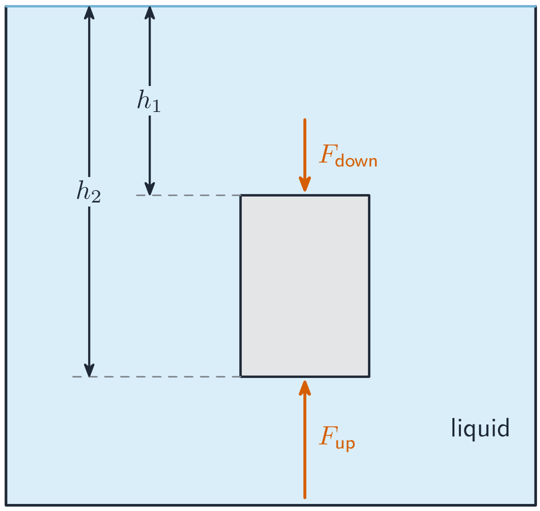
Each idea has a worked example before the Practice.

New ideas

■ 1 The buoyant force

A fluid pushes up on anything in it with a **buoyant force** 浮力 equal to the weight of the fluid the object pushes aside – **Archimedes' principle** 阿基米德原理:

$$F_b = \rho_{\text{fluid}}\, g\, V_{\text{displaced}}.$$



2 Float or sink

Compare the buoyant force with the weight:

- floats when buoyancy balances weight,
- sinks when the weight wins.

Worked example. A block of density 600 kg/m^3 floats in water (1000 kg/m^3). The fraction below the surface is $\dfrac{\rho_{\text{object}}}{\rho_{\text{fluid}}} = \dfrac{600}{1000} = 0.60$ – so 60% sits underwater, the same reason most of an iceberg is hidden.

3 Flowing fluids – continuity

When a fluid flows through a pipe, the same volume must pass every second. So where the pipe is **narrow**, the fluid must flow **faster** – this is **continuity** 连续性:

$$A_1 v_1 = A_2 v_2.$$

Worked example. Water flows at 2.0 m/s in a pipe of area 0.010 m^2, then reaches a narrow section of 0.0040 m^2: $v_2 = \dfrac{A_1 v_1}{A_2} = \dfrac{0.010 \times 2.0}{0.0040} = 5.0$ m/s.

4 Fast flow, low pressure

Where a fluid flows faster, its pressure **drops** – **Bernoulli's** 伯努利 idea. This is why a fast stream of air over a wing lifts a plane, and why shower curtains get sucked inward.

Watch out: a floating object does not have "no weight" – its weight is exactly balanced by the buoyant force pushing up. The two forces are equal, not absent.

Practice

Try these in order. The methods are all above.

2.1 State the direction of the buoyant force on an object in water, and what it equals (in words). [2]

2.2 An object of density 800 kg/m^3 floats in water (1000 kg/m^3). Find the fraction that sits below the surface. [2]

2.3 Water flows at 3.0 m/s in a pipe of area 0.020 m^2. Find its speed where the pipe narrows to 0.0060 m^2. [3]

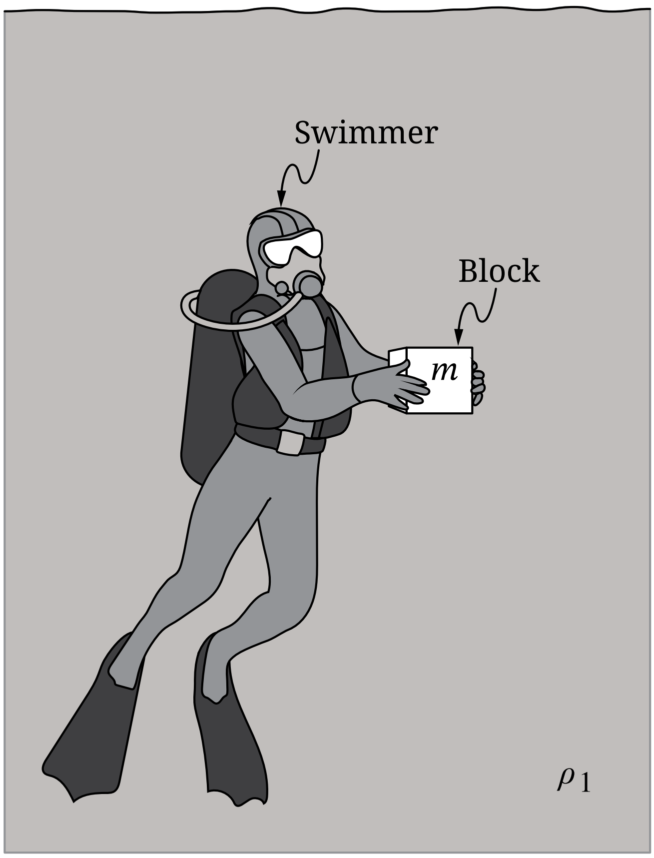
2.4 Explain why water speeds up when a pipe becomes narrower. [2]

2.5 A ball is held underwater and released. Explain, in terms of forces, why it rises. [2]

Question 4

4. In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1



In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

A. Indicate whether a_1 is greater than, less than, or equal to a_2 by writing one of the following in your answer booklet.

- $a_1 > a_2$
- $a_1 < a_2$
- $a_1 = a_2$

Justify your answer in terms of ALL forces exerted on the block in each scenario. Use qualitative reasoning beyond referencing equations.

B. Consider the general case where a block of mass m and volume V is completely submerged in a fluid of density ρ.

Starting with Newton's second law, **derive** an expression for the initial upward acceleration a of the block when the block is released from rest. Express your answer in terms of m, V, ρ, 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 for the acceleration a you derived in part B is or is not consistent with the claim made in part A. Briefly **justify** your answer by referencing your derivation in part B.

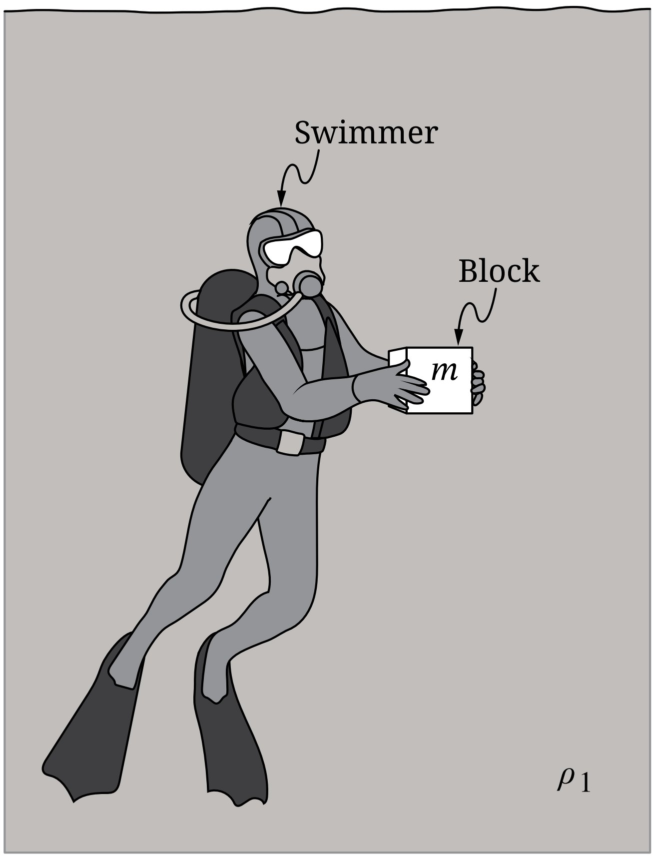
STOP

END OF EXAM

Question 4

4. In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1



In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

A. Indicate whether a_1 is greater than, less than, or equal to a_2 by writing one of the following in your answer booklet.

- $a_1 > a_2$
- $a_1 < a_2$
- $a_1 = a_2$

Justify your answer in terms of ALL forces exerted on the block in each scenario. Use qualitative reasoning beyond referencing equations.

B. Consider the general case where a block of mass m and volume V is completely submerged in a fluid of density ρ.

Starting with Newton's second law, **derive** an expression for the initial upward acceleration a of the block when the block is released from rest. Express your answer in terms of m, V, ρ, 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 for the acceleration a you derived in part B is or is not consistent with the claim made in part A. Briefly **justify** your answer by referencing your derivation in part B.

STOP

END OF EXAM