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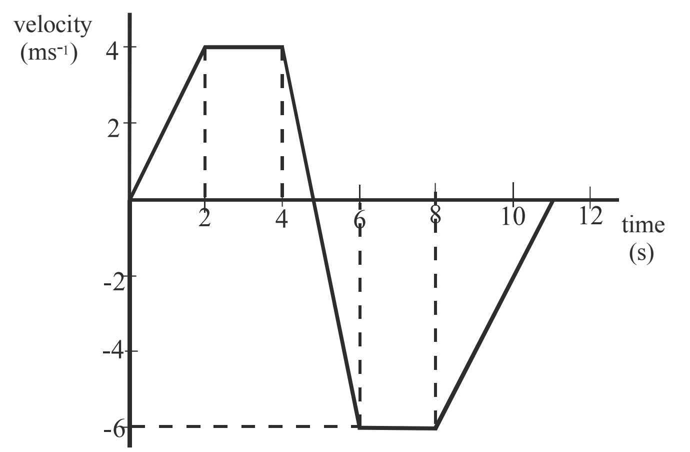
MECHANICS

GENERAL NOTES:

- In this study guide the value for gravitational acceleration will be taken as 9,8 ms^{-2}.
- We use the subscript i for initial values of a certain interval and f for the final values of the interval. For example, v_i will be the initial velocity of a certain interval (instead of u as used in some textbooks) and v_f will be the final velocity of the interval (instead of just v as used in some textbooks.)

PROBLEM 1: GRAPHS OF MOTION

The path of a moving particle is limited to a straight line running north-south. Use a coordinate system where north is positive. The accompanying graph gives the velocity as a function of time. The graph intersects the horizontal axis at 4,8 s and 11 s.



1.1 Complete a table in which you indicate the directions of the velocity in one column and the acceleration in another column for the following instants: 1,0s, 3,0s, 4,2s, 5,0s, 7,0s, 10,0s. In a third column indicate whether the object is moving slower, faster, or maintaining a constant speed.

Time	Velocity	Acceleration	faster/slower
1,0s	North (+)	North (+)	faster
3,0s	North (+)	zero	constant speed
4,2s	North (+)	South (-)	slower
5,0s	South (-)	South (-)	faster
7,0s	South (-)	zero	constant speed
10s	South (-)	North (+)	slower

It is important to note that a negative acceleration does not necessarily mean *deceleration*. As seen from the table above, the directions (signs) of both the velocity and the acceleration indicate whether an object moves faster or slower.

1.2 What is the total displacement of the object during the journey?

Find the area under the graph. The areas below the x-axis are negative.

$$\text{Area} = \tfrac{1}{2}(2)(4) + (2)(4) + \tfrac{1}{2}(0{,}8)(4) - \tfrac{1}{2}(1{,}2)(6) - (2)(6) - \tfrac{1}{2}(3)(6)$$
$$= -11\,\text{m}$$

1.3 What is the average velocity for the entire journey?

Definition of velocity: velocity = displacement ÷ time

$$\vec{v} = \frac{\Delta x}{\Delta t} = \frac{-11\text{m}}{11\text{s}} = -1{,}0\ \text{ms}^{-1}$$

1.4 What is the acceleration
1.4.1. during the first two seconds?
1.4.2 between $t = 4\text{s}$ and $t = 6\text{s}$?

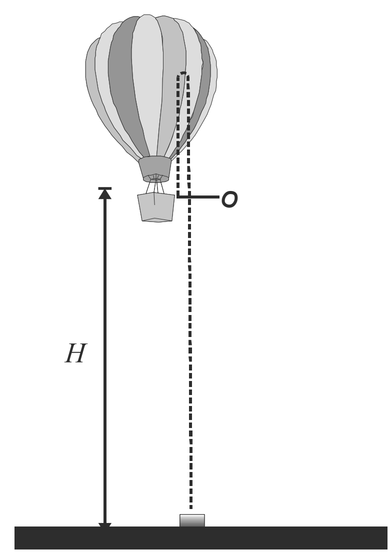
Calculate the gradient of the velocity -time graph.

$$1.4.1\quad a = \frac{\Delta v}{\Delta t} = \frac{4-0}{2-0} = 2\,ms^{-2} \quad \therefore\ 2\,ms^{-2},\ north$$

$$1.4.2\quad a = \frac{\Delta v}{\Delta t} = \frac{-6-4}{6-4} = -5\,ms^{-2} \quad \therefore\ 5\,ms^{-2},\ south$$

PROBLEM 2: VERTICAL PROJECTILE MOTION

A Hot air balloon is ascending with a speed of 5,00 ms^{-1}. A person in the basket releases a bag of flour at a height H. The bag strikes the earth with a speed of 18,0 ms^{-1}.



2.1 How long will the bag be in the air?

Choose a coordinate system with the origin (O) at the point where the bag is released and the positive Y-axis pointing upwards. With this choice of coordinate system, gravitational acceleration will always be negative (whether the bag of flour is moving upward or not), because gravity is always pulling downwards. Remember that all the quantities in the equations of motion are vectors (except time). We therefore need to substitute the signs of these quantities together with their magnitudes. There are two ways to solve this problem:

Method 1

Divide the motion in three parts: ① upward to maximum height, ② from the maximum height downward to the origin, and ③ from the origin downward to the ground.

①For the upward motion:

$$g = -9{,}8\,ms^{-2}$$
$$v_i = +5{,}0\,ms^{-1}$$
$$v_f = 0$$

$$v_f = v_i + gt$$
$$\therefore 0 = 5 - 9{,}8t$$
$$\therefore t_1 = 0{,}51\,\text{s}$$

②For downward motion (from maximum height to the origin):

$$v_i = 0$$
$$v_f = -5{,}0\,\text{ms}^{-1}$$
$$\therefore t_2 = 0{,}51\,\text{s} \;\; \text{(same as for 1)}$$

③From the origin to the ground:

$$a = g = -9{,}8\,\text{ms}^{-2} \qquad v_f = v_i + at$$
$$v_i = -5{,}0\,\text{ms}^{-1} \qquad \therefore -18 = -5 - 9{,}8t$$
$$v_f = -18\,\text{ms}^{-1} \qquad \therefore t_3 = 1{,}33\,\text{s}$$

$$\text{Total time} = t_1 + t_2 + t_3$$
$$= 0{,}51 + 0{,}51 + 1{,}33$$
$$= 2{,}35\text{s}$$

Method 2

Do not divide the motion into sections, but consider the complete motion at once.

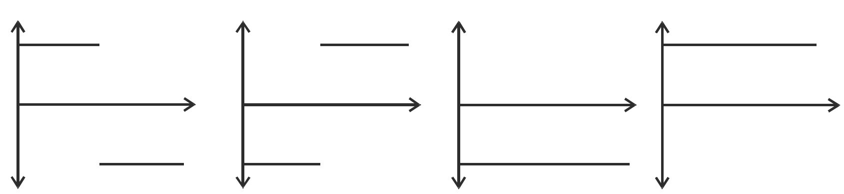
$$a = g = -9{,}8\,\text{ms}^{-2} \qquad v_f = v_i + at$$
$$v_i = 5\text{ms}^{-1} \qquad \therefore -18 = 5 - 9{,}8t$$
$$v_f = -18\,\text{ms}^{-1} \qquad \therefore t = 2{,}35\text{s}$$

2.2 Find H, the height from which the bag was released.

Again consider the complete motion.

$$v_i = 5\,\text{ms}^{-1} \qquad s = v_i t + \tfrac{1}{2}at^2$$
$$a = -9{,}8\,\text{ms}^{-2} \qquad = (5)(2{,}35) + \tfrac{1}{2}(-9{,}8)(2{,}35)^2$$
$$t = 2{,}35\text{s} \qquad = -15{,}3\text{m}$$
$$\therefore H = 15{,}3\,\text{m}$$

2.3 Which one of the graphs below represents the acceleration-time graph for this motion?

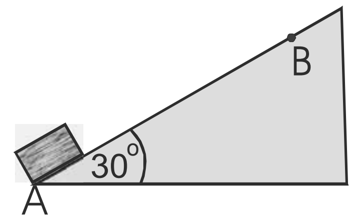


A B C D

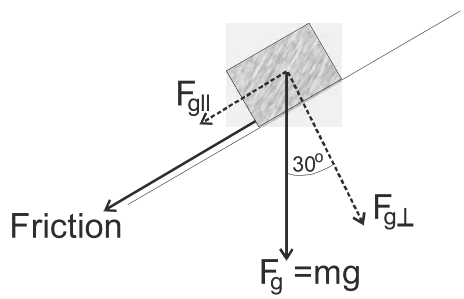
Answer: **C**. A and B are wrong, because they imply that the direction of the acceleration changes after the bag has reached its maximum height, which is of course not true. Gravitational acceleration is always downward. For our choice of coordinate system with the negative y-axis downward, the correct acceleration-time graph is C.

PROBLEM 3: WORK AND ENERGY

A block is kicked at the bottom of an inclined plane (at point A) so that it starts sliding upwards with an initial speed of 2,9 ms^{-1}. The mass of the block is 3,1 kg. A frictional force of 6,5 N is acting on the block. The block comes to rest at point B.



3.1 Draw a force diagram showing the forces acting on the block while it is moving upward.



3.2 Calculate the total work done on the block.

Remember: $W_{tot} = \Delta E_k$ (this is always true)

$$\begin{aligned} W_{tot} &= E_{kf} - E_{ki} \\ &= 0 - \tfrac{1}{2} m v_i^2 \\ &= -\tfrac{1}{2}(3{,}1)(2.9)^2 \\ &= -13\text{ J} \end{aligned}$$

3.3 Calculate the component of the resultant force on the block, parallel to the plane.

$$\begin{aligned} F_{res} &= F_{friction} + F_{gll} \\ &= 6{,}5 + mg\sin 30° \\ &= 21{,}7\text{ N} \end{aligned}$$

3.4 Calculate how far the block will travel up the plane.

Definition of work: $W = F.\,\Delta x$

Both F and Δx are vectors, therefore we should include signs to indicate their directions. Choose a coordinate system with the x - axis parallel to the inclined plane with positive upwards along the plane.

$\therefore F =$ -21,7 N (down the incline) and Δx is positive

$$\begin{aligned} W &= F.\Delta x \\ -13 &= (-21{,}7)\Delta x \\ \therefore \Delta x &= 0{,}60\text{ m} = \text{the distance AB} \end{aligned}$$

PROBLEM 4: CONSERVATION OF ENERGY

A brick of mass 1,2 kg is thrown off a building, 25 m high, with a speed of 1,1 ms^{-1} directly downwards. As it falls onto the earth, it penetrates 15 cm into the ground. Ignore air friction.

4.1 Calculate the speed with which the brick hits the ground. (Note: This can be solved either by equations of motion or by energy principles. Let's use energy conservation in this case.)

Total mechanical energy at the top = Total mechanical energy at the bottom
(This is true, because we ignore air friction)

$$\text{Tot } E_{\substack{\text{mech}\\ \text{at top}}} = \text{Tot } E_{\substack{\text{mech}\\ \text{at bottom}}}$$

$$\therefore (E_k + E_p)_{top} = (E_k + E_p)_{bottom}$$

$$\therefore \tfrac{1}{2}mv_{top}^2 + mgh = \tfrac{1}{2}mv_{bottom}^2 + 0$$

$$\therefore \tfrac{1}{2}v_{top}^2 + gh = \tfrac{1}{2}v_{bottom}^2$$

$$\tfrac{1}{2}(1{,}1)^2 + (9{,}8)(25) = \tfrac{1}{2}v_{bottom}^2$$

$$\therefore v_{bottom} = 22{,}2 \text{ ms}^{-1}$$

Note that in the fourth step, the mass cancels from the equation. It means that if the brick had a different mass its final speed would still be the same.

4.2 Calculate the total work done on the brick as it enters the ground.

$$W_{tot} = \Delta E_k = E_{kf} - E_{ki}$$

Since it comes to rest in the ground $E_{kf} = 0$.

$$W_{tot} = -\tfrac{1}{2}mv_i^2 = -(1{,}2)(22{,}2)^2 = -296\text{J}$$

4.3 Calculate the frictional force exerted by the ground on the brick to bring it to rest. (Let's take downwards as negative.)

$$W_{tot} = F_{res}.\Delta x$$

$$-296 = F_{res}(-0{,}15)$$

$$\therefore F_{res} = 1973 \text{ N}$$

This is not the frictional force yet. F_{res} comprises of the contribution by gravity F_{g} (downward) and friction F_{f} (upward).

$$-F_g + F_f = F_{res}$$

$$-mg + F_f = 1973$$

$$F_f = 1973 + (1{,}2)(9{,}8) = 1985 \text{ N}$$

4.4 Calculate the change in momentum the brick experiences from the moment it hits the ground until it comes to rest. (Take downwards as negative)

$$\begin{aligned}\Delta p &= mv_f - mv_i \\ &= 0 - (1{,}2)(-22{,}2) \\ &= 26{,}6\ \text{kgms}^{-1}\end{aligned}$$

4.5 Calculate the time it takes the brick to come to rest from the moment it hits the ground.

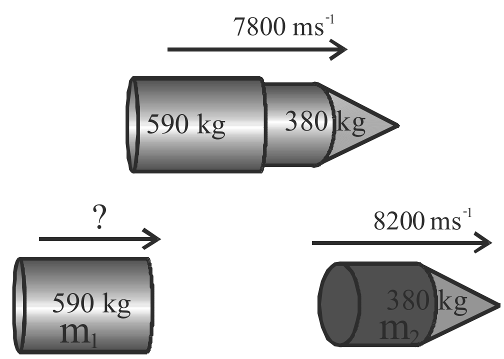
$$\text{Impuls} = \text{change in momentum}$$

$$\begin{aligned}F_{res}.\Delta t &= \Delta p \\ \therefore\ (1973)\Delta t &= -26{,}6 \\ \therefore\quad \Delta t &= 0{,}013\,\text{s}\end{aligned}$$

This is only a fraction of a second, but it is in accordance with our experience. We know that when a brick falls onto the ground it comes to rest almost immediately.

PROBLEM 5: CONSERVATION OF MOMENTUM

A space vehicle consists of a rocket motor with a mass of 590 kg and a capsule with a mass of 380 kg. While the space vehicle is travelling with a speed of 7800 ms^{-1} (as measured from the earth) the rocket motor is disengaged and when a compressed spring is released, the rocket motor is sent away from the capsule. As a result the capsule speeds forward at 8200 ms^{-1} (as measured form the earth).



5.1 What is the speed of the rocket motor after the two sections have been separated?

Total momentum before separation = total momentum after separation

$$\begin{aligned}(m_1 + m_2)u_{(before)} &= m_1 v_1 + m_2 v_2 \\ (590 + 380)(7800) &= (380)(8200) + (590)v_2 \\ v_2 &= 7542\,\text{ms}^{-1}\end{aligned}$$

5.2 An observer in the capsule looks backward at the rocket motor. How fast and in which direction is the rocket motor moving according to him?

The rocket motor is still moving in the original direction (as seen by someone on the earth), but just slower than before the separation. An observer in the capsule will see the motor receding (moving backward) at a speed of (8200-7542) = 658 ms^{-1}. Thus, in the earths reference frame the motor is moving forward at 7542 ms^{-1} and in the reference frame of the capsule, the motor is moving backward at 658 ms^{-1}.

PROBLEM 6: CONSERVATION OF MOMENTUM (2D)

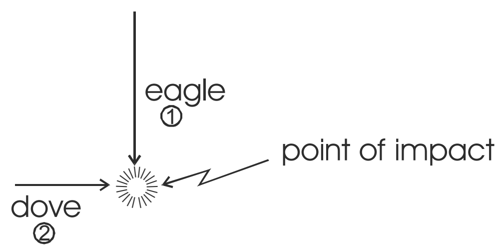
An eagle soaring high in the sky, spots a dove 30 m below, flying horizontally with a speed of 12 ms^{-1}. The eagle goes into a vertical dive and grabs the dove when it is directly below the point where the eagle went into its dive. The mass of the dove is 0,80 kg and the mass of the eagle is 2,1 kg. Assume that the initial vertical speed of the eagle is zero.

6.1 What is the speed of the eagle when it grabs the dove. Choose upwards as positive.

$$y = v_i t + \tfrac{1}{2} g t^2$$
$$-30 = 0 + \tfrac{1}{2}(-9{,}8)t^2$$
$$t = 2{,}5\,\text{s}$$
$$v = gt = -24{,}2\ \text{ms}^{-1}$$

6.2 Calculate the speed of the eagle just after it has grabbed the dove in its claws.

Choose a coordinate system: Positive x is to the right and positive y is upwards.



Momentum is conserved in the X- and the Y -direction:

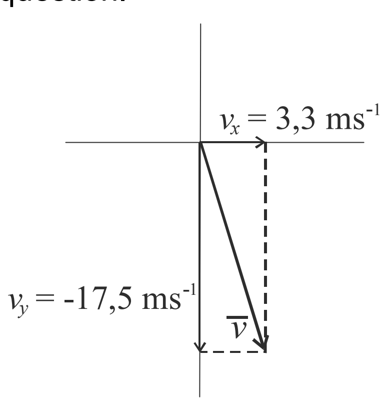
X-direction:

$$m_1 u_{x1} + m_2 u_{x2} = (m_1 + m_2) v_x$$
$$0 + (0{,}8)(12) = (0{,}8 + 2{,}1) v_x$$
$$\therefore \quad v_x = 3{,}3\ \text{ms}^{-1}$$

Y-direction:

$$m_1 u_{y1} + m_2 u_{y2} = (m_1 + m_2) v_y$$
$$(2{,}1)(-24{,}2) + 0 = (2{,}9) v_y$$
$$\therefore \quad v_y = -17{,}5\ \text{ms}^{-1}$$

Now that we have the two components of the velocity, we can find the magnitude of the instantaneous velocity just after the eagle has grabbed the dove, which is the speed required in the question.



$$|\overline{v}| = \sqrt{(3{,}3)^2 + (-17{,}5)^2} = 17{,}8\ \text{ms}^{-1}$$

6.3 Is the collision between the dove and the eagle elastic or inelastic?

For an elastic collision the change in kinetic energy for the whole system is equal to zero.

Kinetic energy of dove + eagle before collision = $(\frac{1}{2}mv^2)_{eagle} + (\frac{1}{2}mv^2)_{dove}$

$$= \tfrac{1}{2}(2{,}1)(24{,}2)^2 + \tfrac{1}{2}(0{,}8)(12)^2$$
$$= 673 \text{ J}$$

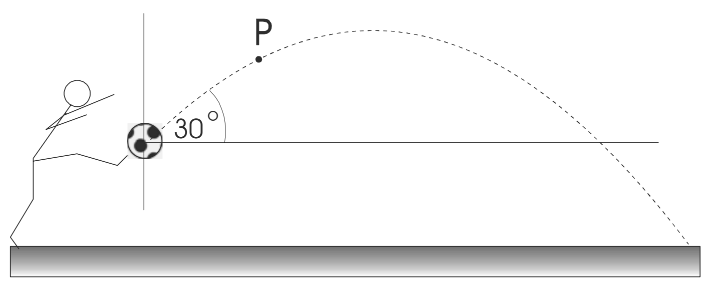
Kinetic energy of dove + eagle after collision = $\frac{1}{2}(2{,}1 + 0{,}8)(17{,}8)^2$

$$= 459 \text{ J}$$

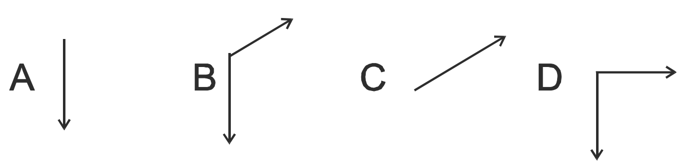
The total kinetic energy decreased significantly. This collision is therefore inelastic.

PROBLEM 7: PROJECTILE MOTION (2D)

A boy kicks a soccer ball and the ball leaves the boy's boot at a height of 0,80 m above the ground with a speed of 8,8 ms^{-1} at an angle of 30° with the horizontal. Ignore air friction.



7.1 Which diagram shows the direction(s) of the force(s) acting on the ball, when the ball is at point P along its trajectory?



Answer: **A** Gravity is the only force acting on the ball during its journey through the air. There are no horizontal forces acting on the ball. As soon as the ball leaves the boy's boot, the force between the ball and the boot ceases to exist. The boot cannot exert a force on the ball without touching it. Someone choosing B as answer, is probably confusing force and momentum. It is true that the ball has momentum in the direction of motion, but one cannot indicated force and momentum on the same vector diagram.

Let us analyse the problem:

X-components	Y-components
$a_x = 0$ $v_x = v_{xi}$ (stays constant) At max. height $v_x = v_{xi}$ displacement $x = v_{xi} \times t$	$a_y = -9{,}8$ ms^{-2} v_y not constant At max. height $v_y = 0$ displacement: $y = v_{yi}\, t + ½ gt^2$

7.2 Write the x- and y-components of the initial velocity.

$$v_{xi} = 8{,}8\cos 60°\ \text{ms}^{-1} = 4{,}4\ \text{ms}^{-1}$$
$$v_{yi} = 8{,}8\sin 60°\ \text{ms}^{-1} = 7{,}6\ \text{ms}^{-1}$$

7.3 Calculate the maximum height the ball reaches above the ground.

This question requires us to look at the vertical motion (y-components). When the ball reaches its maximum height v_y = 0.

$$v_y = v_{yi} + gt$$
$$\therefore 0 = 7{,}6 - 9{,}8t$$
$$\therefore t = 0{,}775 = 0{,}78\ \text{s}$$

$$y = v_{yi}t + \tfrac{1}{2}gt^2$$
$$\therefore y = (7{,}6)(0{,}78) + \tfrac{1}{2}(-9{,}8)(0{,}78)^2$$
$$\therefore y = 2{,}9\ \text{m}$$

The height above the ground = 2,9 m + 0,8 m = 3,7 m

7.4 Calculate how far the boy kicks the ball, that is, what distance from the boy's boot does the ball fall to the ground.

When the ball reaches the ground y = -0,80 m. (That is 0,8 m below the point where the ball was kicked). This question asks us to find x when y = -0,8 m. First find the time it takes the ball to reach the ground.

$$y = v_{yi}t + \tfrac{1}{2}a_y t^2$$
$$-0{,}8 = 7{,}6t - \tfrac{1}{2}(9{,}8)t^2$$

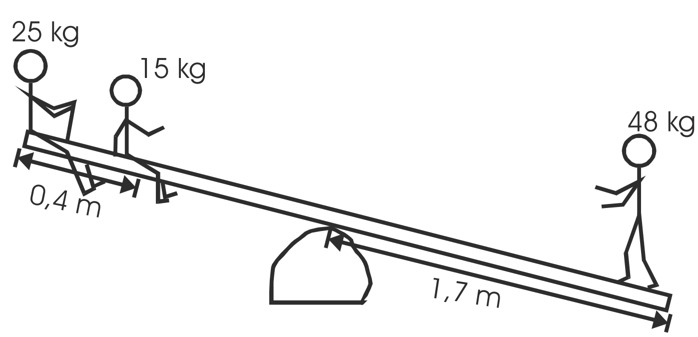
Solve for t: $t = 1{,}65\ \text{s}$

Substitute in x:

$$x = v_x t$$
$$\therefore\ x = (4{,}4)(1{,}65) = 7{,}3\ \text{m}$$

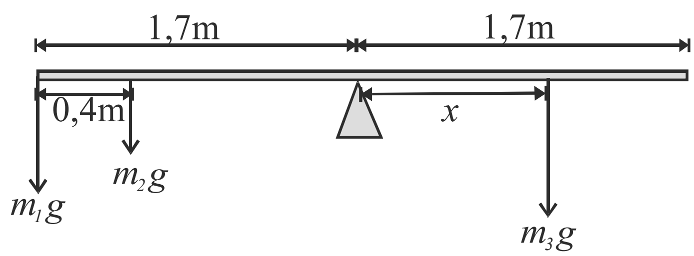
PROBLEM 8: MOMENT OF FORCE

Three children are playing on a see-saw they made by balancing a 3,4 m long plank on a rock in the middle of the plank. The plank is homogeneous. The two smallest children (with masses m_1 = 25 kg and m_2 = 15 kg) sit on the left side (0,40 m apart) as shown in the diagram. When the oldest child (mass m_3 = 48 kg) stand on the right end, that end touches the ground. How far must the oldest child walk along the plank towards the rock, so that the see-saw will balance horizontally again?



Remember: Moment of force: $\tau = F \times l$, where F is an applied force and l the distance from the point where the force is applied to the pivot point.

First draw a force diagram:



We will apply the following principle: the sum of clockwise moments = the sum of counter clockwise moments.

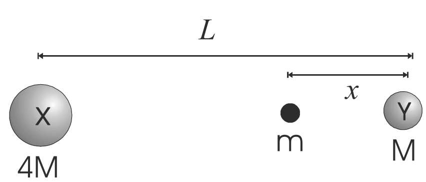
(We do not take the mass of the plank and the effect gravitation has on the plank into account, because the plank is homogeneous and balanced in the middle. (Homogeneous means that the plank has the same density right through and that it will balance in the middle when it has nothing on it) Gravitation has therefore no moment (rotating effect) on the plank itself.)

$$m_3 gx = m_1(1{,}7) + m_2 g(1{,}3)$$
$$(\div g)$$
$$(48)x = (25)(1{,}7) + (15)(1{,}3)$$
$$\therefore \quad x = 1{,}3\,\text{m}$$

$\therefore$ distance that the oldest child will walk $= 0{,}4$ m

PROBLEM 9: GRAVITY

The distance between the centres of two spheres, X and Y, is L. The mass of X is 4 times that of Y. Where, measured from Y, is the gravitational force on an object between the spheres, equal to zero?



A. ½L B. ⅓L C. ¼L D. ⅛L

Answer: **B**

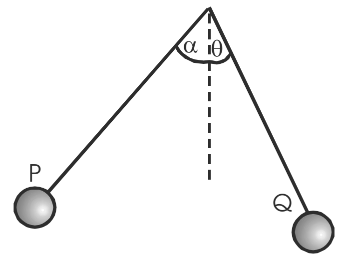
Consider the diagram: Let the mass of Y be M, then the mass of X is 4M. The mass of the other object is m. We require the force of X on m (F_{Xm}) to be equal the force of Y on m (F_{Ym}).

$$F_{\text{Xm}} = F_{\text{Ym}}$$
$$\frac{G(4M)m}{(L-x)^2} = \frac{GMm}{x^2}$$
$$4x^2 = (L-x)^2$$
$$x = \tfrac{1}{3}L$$

ELECTRICITY AND MAGNETISM

MULTIPLE CHOICE QUESTIONS

1. The diagram shows a setup where two spheres (P and Q), attached to thin strings, have been charged positively. The two angles that the strings make with the vertical are not equal. A possible reason for this is



A. The force Q exerts on P is greater than the force P exerts on Q
B. The charge on Q must be more than charge on P
C. Q must be heavier than P
D. none of the above

Answer: **C**
According to Newton's third law, the force Q exerts on P is equal in magnitude to the force P exerts on Q. Therefore A and B is wrong, because they both violate Newton's third law. The only reason why the electrostatic repulsion between the two spheres (as calculated by Coulomb's law) cannot lift Q as high as it does P, is because Q has a greater weight than P.

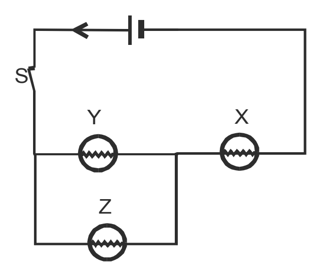
2. In which unit is the work done on a unit charge, as it moves from one point in a circuit to another, measured?
A. Ampere
B. Volt
C. Ohm
D. Watt

Answer: **B,** $V = \dfrac{W}{q}$ (volt = joule/coulomb)

3. Which energy transfer is mainly taking place when charged particles move through a cell with low internal resistance?
A. chemical energy to electric potential energy
B. chemical energy to kinetic energy
C. kinetic energy to electric potential energy
D. heat to kinetic energy?

Answer: **A**

4. If all the bulbs in the circuit are identical and the resistance of the conductors and the cell is negligible, how does the brightness of bulb X compare with that of bulb Y?



A. X is brighter than Y
B. the same
C. X is dimmer than Y

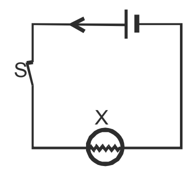
Answer: **A** Y and Z will glow much dimmer than X.

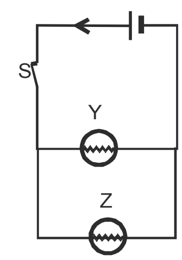
Let us assume that at the instant we compare the brightness of the bulbs, the resistances of the three bulbs are equal (see note below). Say $R = 2\ \Omega$ for all the bulbs. If the current through X is1 A, the current through Y is 0,5 A. The power in each bulb is the rate at which electrical potential energy is converted to light and heat and can be an indication of the brightness of the bulb:

$$P_X = I^2R = (1)^2(2) = 2\ \mathrm{W}$$
$$P_Y = (0{,}5)^2(2) = 0{,}5\mathrm{W}$$

(Note: Because X glow brighter than Y and Z, the temperature of X is higher than that of Y and Z. Since the temperature influences the resistance of a wire, the resistance of the three bulbs are probably not exactly the same as we would expect of identical bulbs)

5. If all the components in these circuits are identical and the resistance of the conductors and the cell is negligible, how does the brightness of bulb X compare with that of bulb Y?

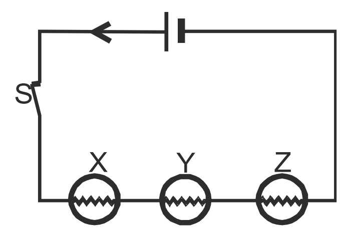




A. X is brighter than Y
B. the same
C. X is dimmer than Y

Answer: **B,** the voltage across the two bulbs is the same and they have the same resistance. The power $P = \frac{V^2}{R}$ is the same for both.
Note: Remember that the resistance of filament light bulbs are influenced by the temperature of the filament. It might happen that if you close the circuit on the left long before the other one, that particular bulb will reach a higher temperature and won't have the same resistance as the others any more. For the situation above, we assumed that the bulbs have the same resistance at the instant the comparison of brightness was done.

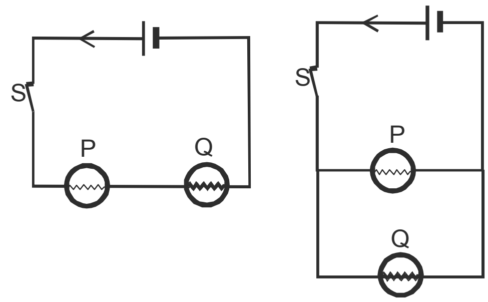
6. The diagram shows an electric circuit with three different light bulbs X, Y and Z. When switch S is closed, we find that bulbs X and Y are glowing, but not bulb Z. The reason for this is that .....



A. Z has fused
B. the resistance of Z is too low
C. the resistance for Z is too high
D. the current is to weak by the time it reaches Z

Answer: **B**, If Z has fused, the circuit will be broken and none of the bulbs will glow - so A is wrong. A bulb glows because the filament gets hot and that happens because the resistance of the filament is high. If the resistance is low the filament won't get hot and the bulb will not glow.

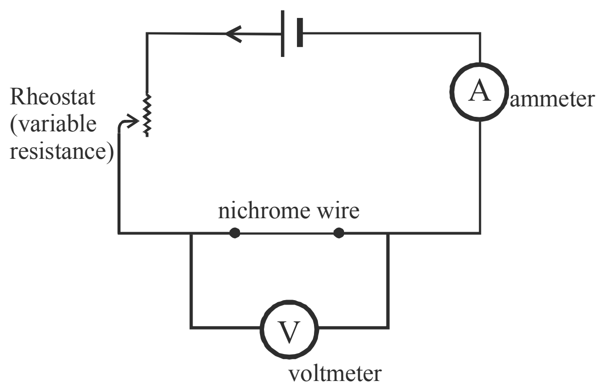
7. Two light bulbs, one with a thin filament (P) and the other with a thicker filament (Q) but of the same length and material as P, are connected in circuits consecutively, as shown. The cells are identical with negligible internal resistance. Compare the brightness of P with that of Q in each circuit. Choose from the table below the correct combination.



	Series circuit	Parallel circuit
A	P is dimmer than Q	P is dimmer than Q
B	P is dimmer than Q	P is brighter than Q
C	P is brighter than Q	P is dimmer than Q
D	P is brighter than Q	P is brighter than Q

Answer: **C.** P has a higher resistance than Q. In the series circuit the current is the same through both bulbs. Looking at $P = I^2 R$ we see that the power in the bulb with the highest resistance is the highest and therefore will glow the brightest. In the parallel circuit the potential difference across the bulbs is the same and from $P = \frac{V^2}{R}$ we see that the bulb with the highest resistance has the lowest power and will therefore glow dimmer.

8. Susan reads in her science textbook that for a certain type of resistor, the ratio of the potential difference (V) across the resistor to the current through the resistor (I) stays constant as long as the temperature of the resistor does not change. She wants to check if this is true for a piece of nichrome wire by connecting it in a circuit similar to the one in the diagram. If Susan did the investigation correctly, which one of the tables below can be a representation of her data?

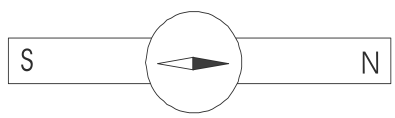


A	V (volt)	I (ampere)	B	V (volt)	I (ampere)
	1,0	0,2		0,50	0,10
	1,0	0,2		0,95	0,19
	1,0	0,2		1,45	0,28
	1,0	0,2		1,70	0,35
	1,0	0,2		1,90	0,38

C	V (volt)	I (ampere)	D	V (volt)	I (ampere)
	1,1	0,20		1,0	0,2
	1,0	0,19		1,0	0,3
	0,9	0,21		1,0	0,4
	0,9	0.20		1,0	0,5
	1,0	0,21		1,0	0,6

Answer: **B**

9. We place a compass right on top of a bar magnet and see that the orientation of the compass needle is as shown in the diagram.

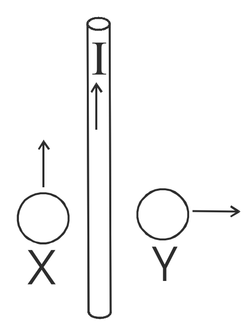


We remove the compass from the bar magnet and let the needle orientate itself in the magnetic field of the earth. In which direction will the black end of the compass needle point?

A. to the North
B. to the South
C. It depends on whether we are in the northern or southern hemisphere.

Answer: **B**. The magnetic pole in the Earth's Southern Hemisphere (near the south geographic pole) is actually the north pole of the Earth's magnetic dipole.

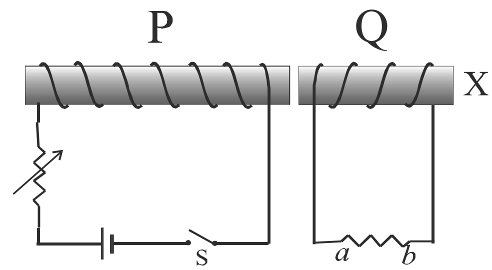
10. The diagram shows a section of a long straight conductor carrying a constant current to the top of the page. Two metal rings (X and Y) on opposite sides of the conductor are being moved in the directions shown in the diagram. The current(s) induced in the two metal rings (X and Y) can be described by



A. X: No current induced, Y: clockwise
B. X: clockwise, Y: counter clockwise
C. X: counter clockwise, Y: clockwise
D. X: No current induced, Y: counter clockwise
E. X: counter clockwise, Y: no current induced

Answer: **A**, at a constant distance from the wire, the magnetic field is constant, so there is no change in magnetic flux through loop X as it moves parallel to the wire and therefore no induced current. As loop Y moves away from the wire the field lines going into the page through loop Y decreases, and according to Lenz's law a clockwise current will be induced in Y.

11. Two sets of coils of insulated wire are wound around two cardboard tubes and connected in circuits as shown in the diagram. A student is experimenting with this by changing something in the setup to create different situations. She also uses a compass to see what the induced magnetic pole at X will be.



Situation (i): Coil P is being moved towards the left, while S is closed.
Situation (ii): By means of the rheostat, the resistance in circuit P is gradually increased

Decide in each situation what the induced magnetic pole at X will be.

	Situation (i)	Situation (ii)
A	North	North
B	South	South
C	North	South
D	South	North

Answer: **A**

12. Magnets attract
A. only iron, nickel and cobalt
B. all metals except aluminum
C. all metals
D. only steel

Answer: **A**

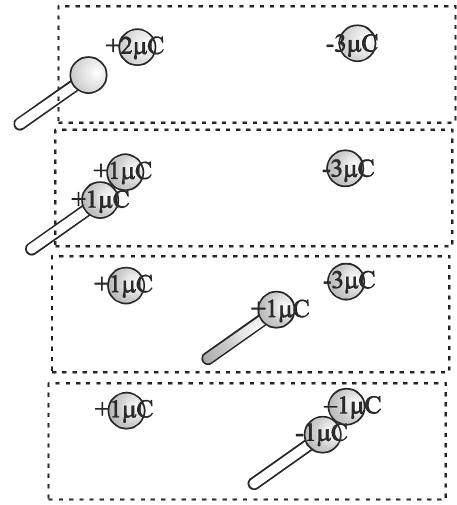
PROBLEM 1: COULOMB'S LAW

Two small conducting spheres (A and B) are charged with +2,0 μC and -3,0 μC respectively and placed at a distance of 5,0 cm from each other and experience an attractive force F. A third uncharged, conducting sphere with an insulating handle is brought into contact with the first sphere (A) and then, without touching anything else, brought into contact with B. By which distance should A and B be separated now, to experience the same force of attraction, F, between them as before?

First find the initial force of attraction between the spheres.

$$F = \frac{kq_1q_2}{r^2}$$
$$F = \frac{(9\times10^9)(2\times10^{-6})(3\times10^{-6})}{(0{,}05)^2}$$
$$F = 21{,}6\,\mathrm{N}$$

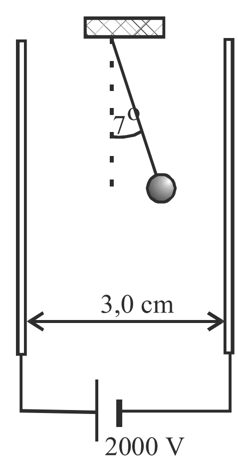
Find out what the final charges on the spheres will be after contact with the third sphere. See the diagram.



We see that the final charges on the two spheres are +1,0 μC and -1,0 μC. The attractive force between them must be 21,6 N as required by the question.

$$21{,}6 = \frac{(9\times10^9)(10^{-6})(10^{-6})}{r^2}$$
$$\therefore\ r = 0{,}0204\ \mathrm{m}$$
$$\therefore\ r = 2{,}0\,\mathrm{cm}$$

PROBLEM 2: A CHARGED PARTICLE IN A UNIFORM FIELD



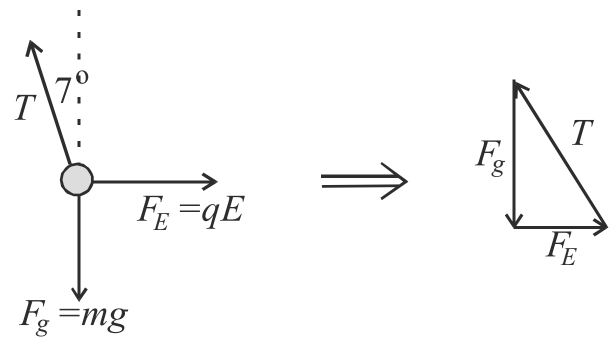
A small, charged sphere is suspended on a very light string between two oppositely charged parallel plates, as shown in the diagram. The plate separation is 3,0 cm and the potential difference between the plates is 2000 V. The mass of the sphere is 8,0 g and the angle between the string and the vertical is 7,0°.

2.1 Calculate the electric field between the plates.

$$E = \frac{V}{d}$$
$$\therefore\ E = \frac{2000}{0{,}03} = 6{,}67\times10^4\ \mathrm{Vm^{-1}}$$

2.2 Calculate the charge on the sphere. Give the answer in nC.

The forces acting on the sphere are in equilibrium.

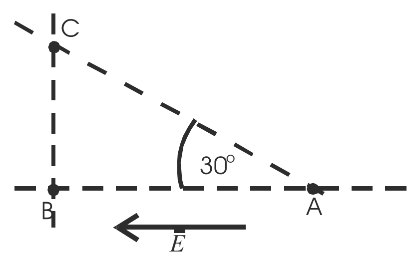


$$
\begin{aligned}
F_E &= F_g \tan 7° \\
&= (0{,}008)(9{,}8) \tan 7° \\
&= 9{,}63 \times 10^{-3}\,\text{N}
\end{aligned}
$$

$$
\begin{aligned}
&\therefore qE = 9{,}63 \times 10^{-3}\,\text{N} \\
&\therefore q = 1{,}44 \times 10^{-7}\,\text{C} = 144\,\text{nC}
\end{aligned}
$$

PROBLEM 3: WORK AND ENERGY IN AN ELECTRIC FIELD

A particle with mass $3{,}00 \times 10^{-23}$ kg and charge + 1,50 nC moves in a uniform field from rest from point A to point B where its speed is found to be $2{,}00 \times 10^{6}$ ms^{-1}. Point A and point B are separated by 5,00 cm.



3.1 How much work is done on the particle by the field?

$$
\begin{aligned}
W = \Delta E_k &= E_{kB} - E_{kA} \\
&= \tfrac{1}{2} m v_B^2 - 0 \\
&= \tfrac{1}{2}(3 \times 10^{-23})(2 \times 10^{6})^2 \\
&= 6{,}0 \times 10^{-11}\ \text{J}
\end{aligned}
$$

3.2 Find the potential difference between points A and B and explain what the answer means in terms of the definition of potential difference.

$$V_{AB} = \frac{W_{A\to B}}{q} = \frac{6 \times 10^{-11}}{1{,}5 \times 10^{-9}} = 0{,}04\ \text{V}$$

This means that 0,04 joules of work is done (by the field) per unit charge to move the charged particle from point A to point B.

3.3 Find the magnitude of the electric field.

$$E = \frac{V}{d} = \frac{0{,}04}{0{,}05} = 0{,}8\,\text{Vm}^{-1}$$

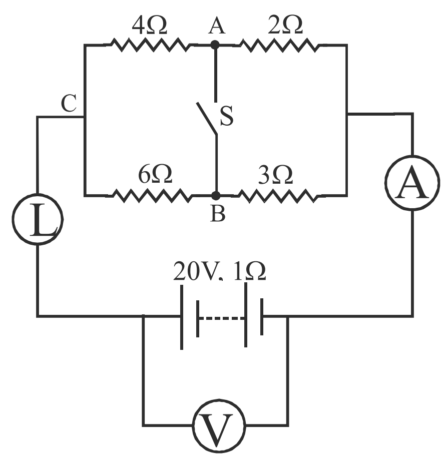
3.4 An identical particle is moved by an external force from point C to point A. How much work is done by this force? Explain your answer.

$$W = 6{,}0 \times 10^{-11}\,\text{J}$$

Since the field is uniform, point B and point C are at the same electric potential. It means that a given charged particle will have the same electrical potential energy at C than is has at B and therefore the same amount of work will be done to take a particle from C to A as will be done by the field to take the particle from A to B.

PROBLEM 4: ELECTRIC CIRCUIT

A circuit is connected as shown in the diagram. The lightbulb L has a resistance of 0,4Ω. The effect the temperature has on the resistance of the lightbulb can be ignored.



4.1 With switch S open, determine the effective resistance, R_{eff}, of the circuit, battery included.

For the parallel combination: $\frac{1}{R} = \frac{1}{4+2} + \frac{1}{6+3} = \frac{5}{18}$

$$\therefore R_{parallel} = 3{,}6\,\Omega$$

$$R_{eff} = 3{,}6 + 0{,}4 + 1 = 5\Omega$$

4.2 Calculate the reading on the ammeter with S still open.

$$I = \frac{V}{R} = \frac{20}{5} = 4\,\text{A}$$

4.3 Calculate the reading on the voltmeter with S still open.

The reading on the voltmeter gives the amount of energy that is available to the circuit per unit charge that leaves the battery. If the battery had no internal resistance all 20 joules of energy (per unit charge) would be available to the rest of the circuit. But now, because of the internal resistance, some of the energy is converted to heat right inside the battery and is not available to the circuit. This amount is often called the “lost volts”.

So, the voltmeter reading is equal to the total amount of energy that the battery can provide (per unit charge), that is the emf (ε), minus the energy converted to heat before the charge left the battery, that is Ir.

$$V = \varepsilon - Ir$$

$$\therefore\ V = 20 - (5)(1) = 15\,\text{V}$$

4.4 With S still open, determine the potential difference (voltage) between A and B.

Voltage across the parallel combination: $V = IR = (4)(3{,}6) = 14{,}4$ V
Now we can calculate the currents through the top and bottom branches of the parallel section.

$$\therefore I_{top} = \frac{14{,}4}{(4+2)} = 2{,}4\text{ A} \quad \text{and} \quad I_{bottom} = \frac{14{,}4}{(6+3)} = 1{,}6\text{ A}$$

$$\therefore V_{CA} = I_{CA}R = (2{,}4)(4) = 9{,}6\text{ V} \qquad \text{and} \qquad V_{CB} = I_{CB}R = (1{,}6)(6) = 9{,}6\text{ V}$$

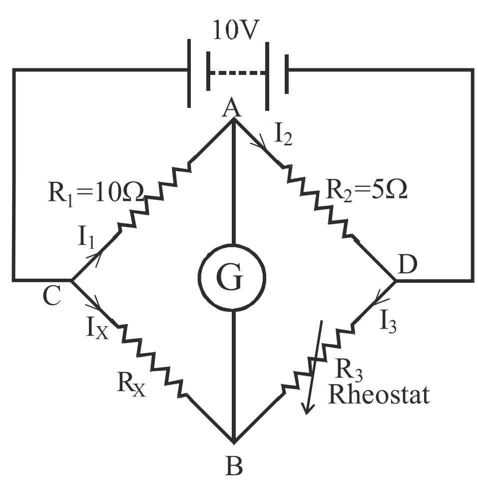
Thus, the potential at A is equal to the potential at B and there is no potential difference between A and B. $V_{AB} = 0$ V.

4.5 Switch S is now closed. What will be the effect on the brightness of the lightbulb?

No effect, since there was no potential difference between A and B, no current will flow from A to B when the switch is closed and the current in the circuit will not be affected.

PROBLEM 5: THE WHEATSTONE BRIDGE

The Wheatstone bridge is a device used to measure resistance very accurately. With the setup below we want to measure the resistance of R_X. At first we see that the galvanometer registers a current between A and B when the rheostat is set at 6Ω.



5.1 What should be done to be able to measure the resistance of R_X?

We should vary the resistance of the rheostat until no current registers on the galvanometer. When that is the case, we know that $V_{AB} = 0$ or $V_A = V_B$, and therefore $V_{CA} = V_{CB}$ and $V_{AD} = V_{BD}$. Thus

$$I_1R_1 = I_XR_X$$

$$\text{and} \quad I_2R_2 = I_3R_3$$

$$\therefore \quad \frac{I_1R_1}{I_2R_2} = \frac{I_XR_X}{I_3R_3}$$

But if there is no current between A and B, then $I_1 = I_2$ and $I_X = I_3$

$$\therefore \quad \frac{R_1}{R_2} = \frac{R_X}{R_3}$$

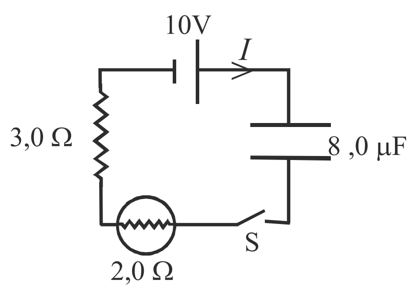
$$\therefore \quad R_X = \frac{R_1 R_3}{R_2}$$

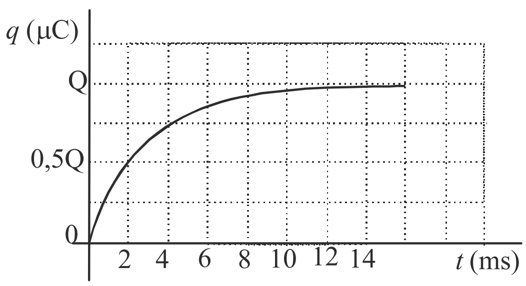
5.2 If we set the rheostat to 8Ω, we see that the reading on the galvanometer is zero. Find the resistance of R_X.

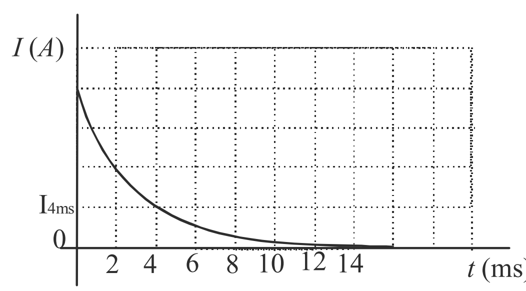
$$R_X = \frac{(10)(8)}{5} = 16\Omega$$

PROBLEM 6: THE RC-CIRCUIT

The capacitor in the circuit, with a capacitance of 8,0 μF, will be fully charged after 12,0 ms from the instant the switch is closed. Included in the circuit is a resistor of 3,0 Ω and a lightbulb with a resistance of 2,0 Ω. The internal resistance of the cell can be ignored. Study the graphs and answer the questions below.







6.1 Calculate the value of Q indicated on graph on the left.

Q is the charge on the capacitor when it is fully charged. When the capacitor is fully charge, the current in the circuit is zero and so, the potential differences across the resistance and the lightbulb are also zero. The potential difference across the capacitor is therefore 10 V.

$$\therefore \quad Q = CV = (8\mu F)(10V) = 80\mu C$$

6.2 Calculate the value of I at 4 ms, indicated on the graph on the right.

First find the initial (maximum) value of the current. At $t = 0$ s the charge on and the voltage across the capacitor is zero. Thus, the voltage across the resistors is 10 V.

$$I = \frac{V}{R} = \frac{10}{5} = 2 \text{ A}$$

The value of I at 4 ms is one quarter of the initial, maximum value, $\therefore I_{4\text{ms}} = 0{,}5$ A.

6.3 Calculate the power in the bulb at 4 ms.

$$P = I^2 R = (0{,}5)^2 2 = 0{,}5 \text{W}$$

6.4 What would be the area of the plates if the plate separation is 5 mm.

$$C = \frac{\varepsilon_0 A}{d}$$

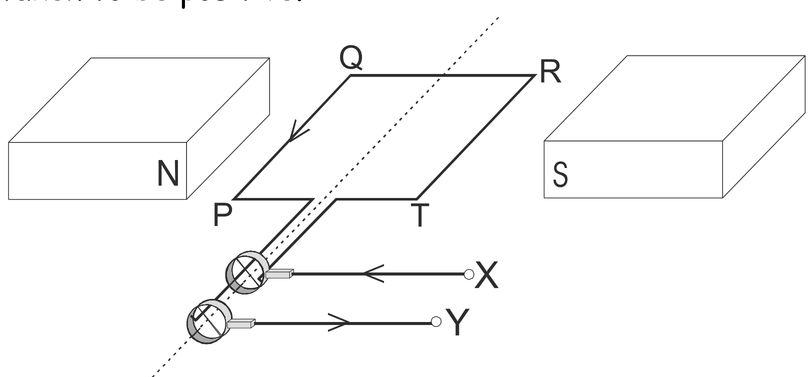
$$8 \times 10^{-6} = \frac{(8{,}85 \times 10^{-12})(A)}{0{,}005}$$

$$\therefore \quad A = 4{,}5 \times 10^3 \text{ m}^2$$

We see that this is an immense area for a circuit component. In reality, “flat” parallel plates are not used in circuits, but rather capacitors which are basically two parallel plates separated by a insulating material, such as plastic, wax or paper, wound up tightly in a cylinder.

PROBLEM 7: AC-GENERATOR

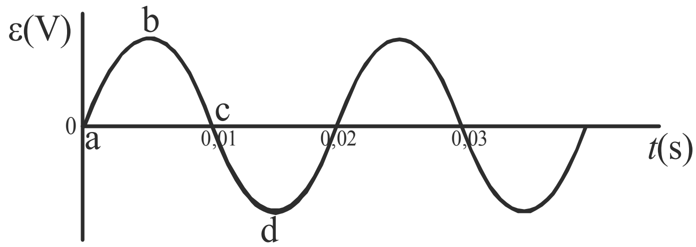
The simplified sketch below shows in principle the operation of the alternating current (AC) generator. When the current goes from X to Y through the generator, the induced emf is taken to be positive.



7.1 In which direction does segment PQ of the coil have to be rotated in order to cause the current direction as shown? Write down clockwise or anticlockwise.

Counter clockwise
Initially there is no current in the loop. As the loop starts to rotate, a current will be induced in the circuit. If PQ moves downward, as a result of a counter clockwise rotation, the magnetic flux from left to right through the loop, will increase. According to Lenz’s law, a current will be induced such that the change will be opposed. Determine with the right hand rule: grab PQ with the fingers pointing through the loop from south to north ⇒ thumb points downward from Q to P.

7.2 Draw the induced emf versus time- graph. Show which point on the graph corresponds to the situation in the diagram above (the loop is horizontal with P to the left of T)

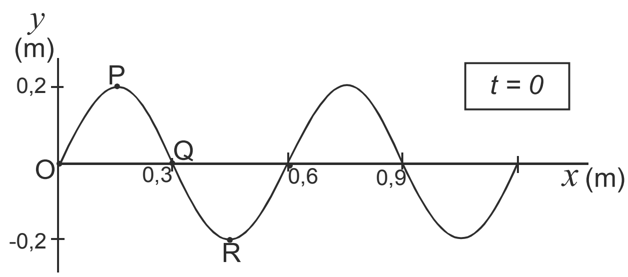


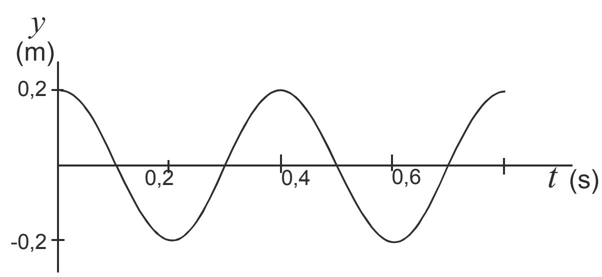
As indicated in the question, the current is positive when it goes from X to Y through the generator. That coincides with the situation in the diagram above and thus with point b on the graph. Points a and c coincides with the situation when the loop is vertical between the magnetic poles - the induced emf is zero when the loop is vertical (minimum change in magnetic flux). At d the loop is horizontal again with T to the left of P and the current flows in the opposite direction.

WAVES, SOUND AND LIGHT

PROBLEM 1: TRANSVERSE WAVES

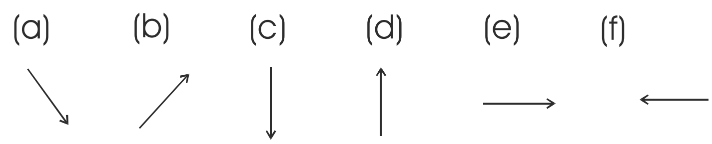
The figure shows two graphs for one and the same wave motion in a given string. The wave is moving towards the right. The first graph shows the vertical displacement of the string as a function of the position of the particles in the string at time t = 0. The second graph shows the vertical displacement of only one of the particles in the string as a function of time .





1.1 What are the amplitude, wavelength, the period, the frequency and the speed of the wave?
Amplitude: $A = 0{,}2$ m
Wavelength: $\lambda = 0{,}6$ m (read from the graph on the left)
Period: $T = 0{,}4$ s (read from the graph on the right)
Frequency: $f = 1/T = 2{,}5$ Hz
Wave speed: $v = f\lambda = 1{,}5$ ms^{-1}

1.2 For each of the points O, P, Q and R on the graph on the left, choose from the possibilities below, a direction in which that particular point will be moving immediately after t = 0.



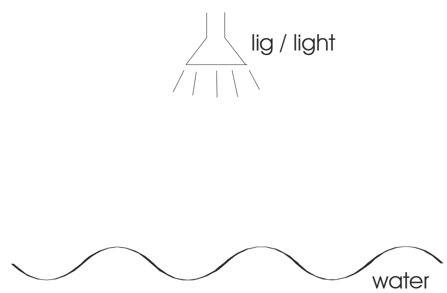
Answer: point O (c); point P (c); point Q (d); point R (d)
This graph can be seen as a snapshot of the string at a certain instant. Every particle in the string is oscillating vertically up and down as the wave travels towards the right in the string. The wave does not transfer particles from one point to another in the direction of motion of the wave.

1.3 Of which point (O, P, Q or R) is the other diagram a position - time graph? Explain your choice.

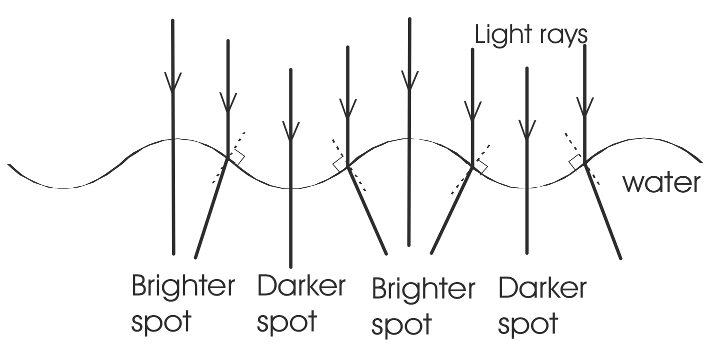
Answer: P. On the instant for which the first graph is drawn, point P has already reached its maximum displacement and will start moving downwards (see question 1.2). This corresponds to the position-time graph showing a particle starting at its maximum displacement and moving downwards.

PROBLEM 2: WAVES IN A RIPPLE TANK

In a ripple tank light is shone from above on shallow water in which little wavelets are made. The diagram shows a side view of the wavelets. The pattern of light and shadowy lines (or circles) that is formed on a white surface below the ripple tank, is a result of the wave pattern. Does a shadowy line correspond to a crest or a trough in the water wave? Explain.



The best way to explain this is to draw a ray diagram indicating the direction of the light rays after refraction at the surface of the water. When light rays travel from an optical less dense medium to a denser medium the rays refract towards the normal. (Remember: the normal is an imaginary line perpendicular to the interface between the two mediums). When a light ray enters the medium along a line perpendicular to the surface it goes through undeflected.

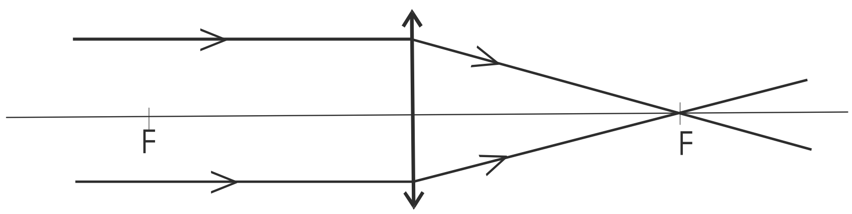


Darker (or shadowy) spots will form if most light rays are directed away from that spot. So we see that the brighter lines form underneath the crests and the shadowy (or darker lines) form underneath the troughs.

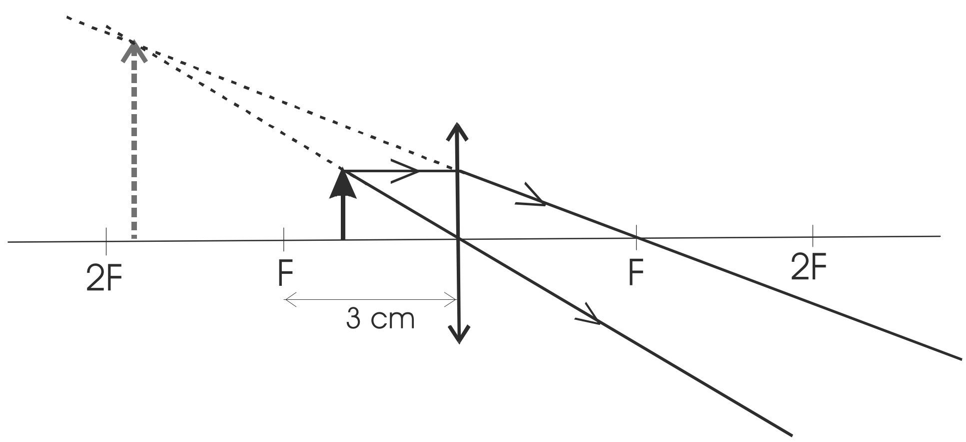
PROBLEM 3: LENSES

Use ray diagrams to indicate image formation in the following cases: Use the symbol ↕ to indicate a convex lens.

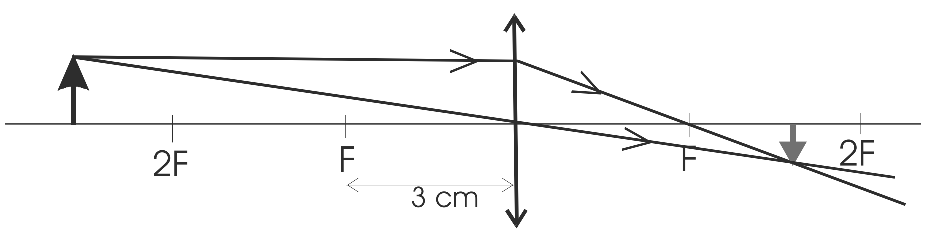
3.1 A convex lens with focal length 5 cm, with light rays coming from a very distant source.
Light rays coming from a very distance source can be considered as being parallel to the main axis and rays parallel to the main axis always converge in the focal point.



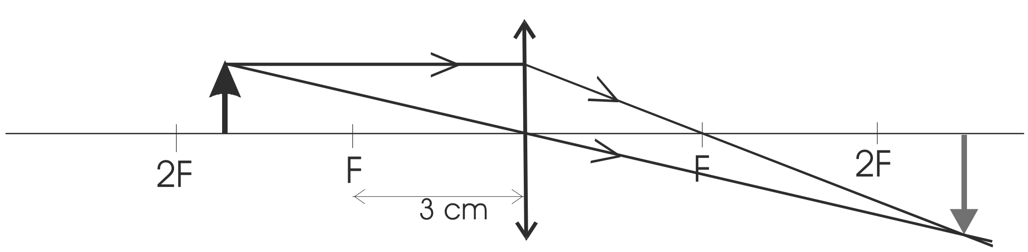
3.2 A convex lens with focal length 3 cm with an object 2 cm to the left of the lens.



3.3 A convex lens with focal length 3 cm with an object 8 cm to the left of the lens.

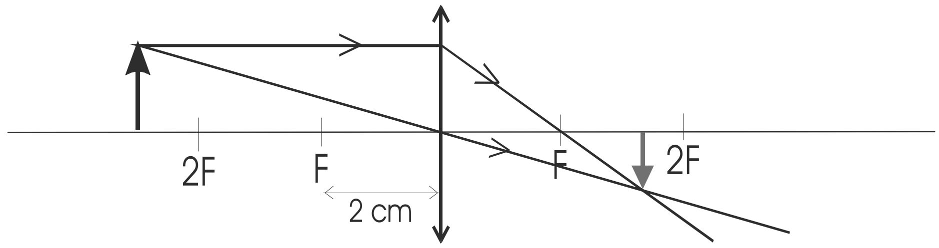


3.4 A convex lens with focal length 3 cm with an object 5 cm to the left of the lens.



3.5 A convex lens with focal length 2 cm with an object 5 cm to the left of the lens. Also say how a lens with shorter focal length differ from a lens with longer focal length.

When a lens has a shorter focal length it is more curved than a lens with a longer focal length.



3.6 Which case above corresponds to:

(i) using a magnifying glass to examine a small object

(ii) burning a hole in a dry leaf using a magnifying glass ,

(iii) image formation in the eye.

Explain your answers.

(i) **3.2** In this case we see a magnified, upright image as is required when we examine small objects with a magnifying glass. We see that if we want to use a lens as a magnifying glass, the object must be between the lens and the focal point.

(ii) **3.1** The sun is a very distant object and the rays from the sun can be considered as falling in parallel to the main axis. The sun's rays will converge in the focal point and the intensity will be high enough to burn something like a dry leaf.

(iii) **3.3 to 3.5** The cornea and the lens of the eye converges light coming from objects further away from the eye than its focal point. The image that forms on the retina is real, inverted and much smaller than the object. (The retina is the light sensitive "film" at the back of the eye on which the images form.)

3.7 Use diagrams 3.3 to 3.5 to explain the function of the lens and eye muscles in the eye.

One should note that we can only see something clearly focussed if the image forms exactly on the retina. If the image forms behind or in front of the retina we will perceive an out of focus or blurred image. The distance between the eye lens and the retina is constant. Thus, if the lens could not adapt in some way to the distance the object is in front of the eye, most of the images will not from exactly on the retina.

When comparing diagrams 3.3 and 3.4 we see that the closer an object is to the lens (provided it is still further away from the lens than the focal point) the further away the image is from the lens. Suppose that 3.3 represents an object distance that is exactly right for a specific eye lens and that the image forms on the retina. If the object now comes closer (as in diagram 3.4) the image will move further away from the lens and form behind the retina.

Now compare diagrams 3.4 and 3.5. Here we see that for a lens with a shorter focal distance the image will form closer to the lens for the same object distance. So, if the lens could become more curved (and have a shorter focal length) when the object is closer to the eye, the image could form exactly on the retina again. This is what the lens muscles do; when an object is close to the eye, the lens muscles contract and in doing so increase the curvature of the lens so that the image still forms on the retina.

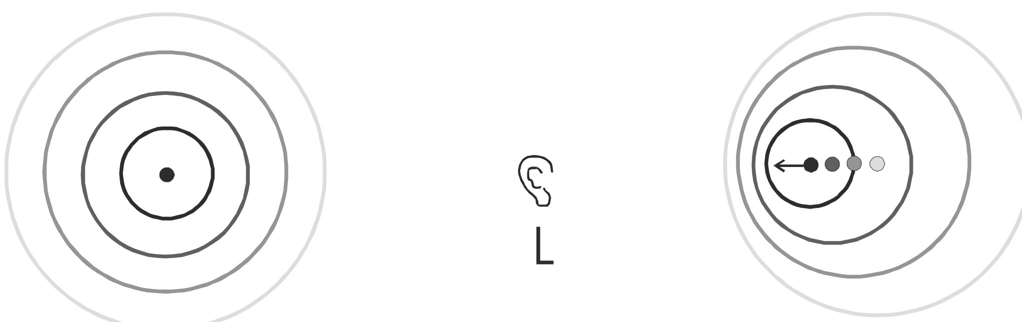
When a person gets older, it often happens that the lens muscles lose their ability to contract and therefore the lens cannot become curved enough for the person to be able to focus on nearby objects and they often need to wear glasses with convex lenses to compensate for the lack of curvature of their own eye lenses.

PROBLEM 4: THE DOPPLER EFFECT

What should I know?

- Frequency - determines the pitch of a sound
  determined by the source of the sound
- Wavefront - "neighbouring" particles in the medium in phase with each other
- Speed of a wave - depends on the medium through which the sound propagates (the density and the elasticity of the medium)

The Doppler-effect can be observed whenever a sound source and a listener or observer are in motion relative to each other. Because of the relative motion, the listener perceives a frequency different from the frequency created by the source. When a source, generating some sound, is moving towards a listener, the listener will perceive a higher sound than when the source is not moving.



Doppler equation

$$f_L = \frac{v - v_L}{v - v_s} f_s$$

A boy on a bicycle, riding with a speed of 6,5 ms^{-1}, is approaching an oncoming train moving with a speed of 26 ms^{-1}. The siren of the train is wailing at a frequency of 415 Hz. Determine the frequency of the sound the boy will perceive. Speed of sound in air = 340 ms^{-1}.

Remark: The speed of sound through air does not have a fixed value. The value depends on the density and the temperature of the air at a particular location.

To solve the problem we need to choose a reference frame. It makes it easier to work with the signs if we choose positive as the direction in which the sound is travelling (that is: from the source towards the listener).

$$f_s = 415\,Hz$$
$$v_s = 26\text{ ms}^{-1}$$
$$v_L = -6{,}5\text{ ms}^{-1}$$
$$f_L = ?$$

$$f_L = \frac{340-(-6{,}5)}{340-26}(415)$$
$$\therefore\ = 458\text{ Hz}$$

PROBLEM 5: THE DOPPLER EFFECT WITH REFLECTION

The sound source of a ship's sonar device operates at a frequency of 30 kHz. A submarine is travelling directly away from the ship with a speed of 24 ms^{-1}. The ship is at rest in the water and sends out a signal which reflects at the moving submarine. After the signal has reflected at the submarine it is detected by the sonar device on the ship. The speed of sound in water is 1480m/s.

5.1 Calculate the frequency of the soundwave as it will be detected by a device on the submarine.

Treat the submarine in this part of the problem as the "listener" L and the ship as the source S. We need to calculate f_L. (Also remember that v_L and v_S is positive when L and/or S move in the same direction as the sound and negative when they move in the opposite direction as the sound.)

$$f_S = 30\,\text{kHz}$$
$$v_L = +24\,\text{ms}^{-1}$$
$$v_S = 0$$
$$f_L = ?$$

$$f_L = \left(\frac{1480-24}{1480}\right)30 = 29{,}5\,\text{kHz}$$

5.2 Calculate the frequency that is detected by ship's sonar device after the reflected signal has arrived at the ship.

In this part of the problem, we treat the submarine as the source, because the sound signal now comes from the submarine. The frequency of the reflected signal is f_S. Here v_S is negative, because the sound is travelling towards the ship, but the submarine is travelling away from the ship.

$$f_L = ?\ \text{(the signal detected by the ship)}$$
$$f_S = 29{,}5\,kHz \quad \text{(the frequency reflected at the submarine} = f_L \text{ of 4.1)}$$
$$v_L = 0$$
$$v_S = -24\,ms^{-1}$$

$$f_L = \frac{1480}{1480+24}29{,}5 = 29{,}0\text{ kHz}$$

By comparing the outgoing signal with the reflected signal the crew on a ship can determine the speed of another vessel moving in its vicinity.