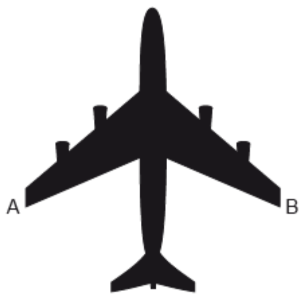
electromagnetic induction 1 *[48 marks]*

1. An aircraft with a wing span of 50 m flies horizontally at a speed of $200\ \mathrm{m\,s^{-1}}$. The vertical component of the Earth's magnetic field at the plane's position is $10\ \mu\mathrm{T}$. *[1 mark]*



What electromotive force (emf) is induced between points A and B on the aircraft?

A. 0.1 V

B. 1 V

C. 10 V

D. 100 V

Markscheme

A

2. Faraday's law of electromagnetic induction states that the electromotive force (emf) induced in a conductor is proportional to *[1 mark]*

A. the change of magnetic flux density.

B. the change of magnetic flux linkage.

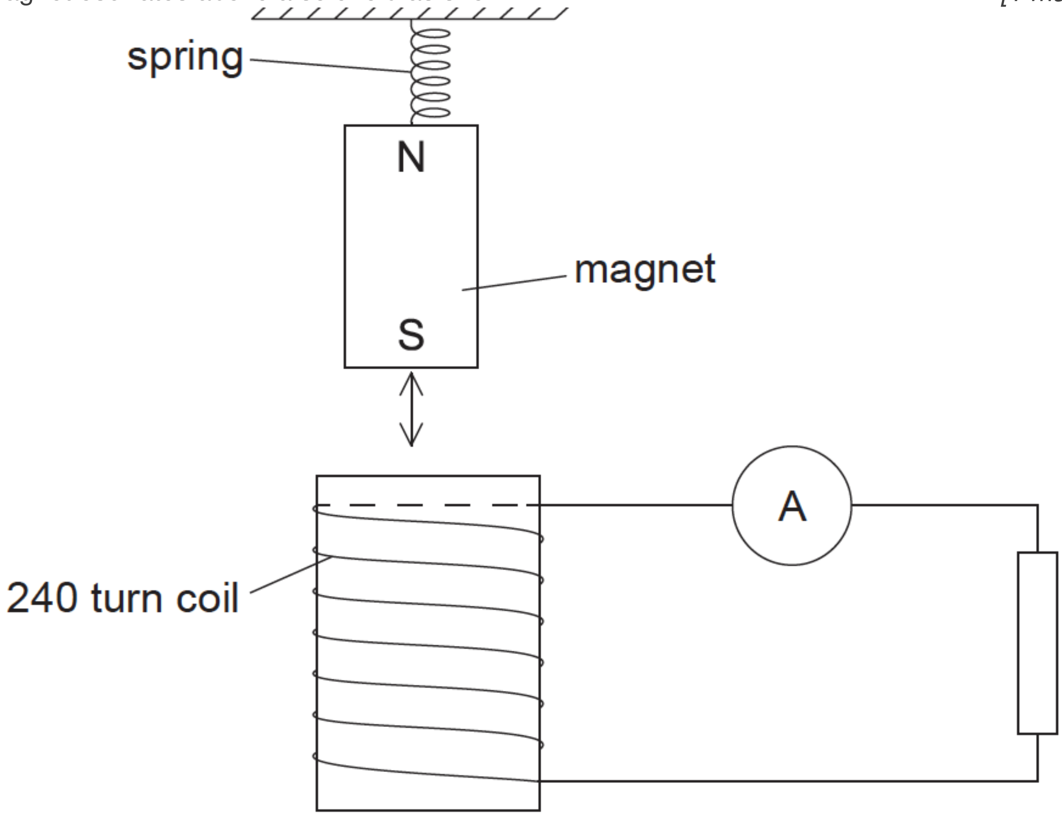
C. the rate of change of magnetic flux density.

D. the rate of change of magnetic flux linkage.

Markscheme

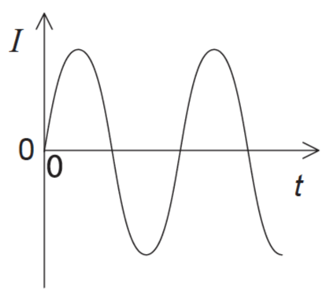
D

3. A magnet oscillates above a solenoid as shown. *[1 mark]*

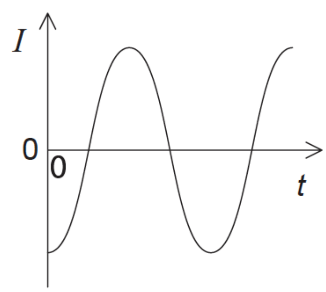


The magnet is displaced vertically and released from its highest position at time t=0. Which graph shows the variation with time t of the current I in the resistor?

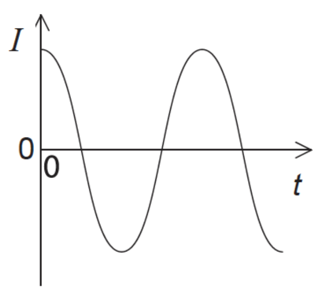
A.



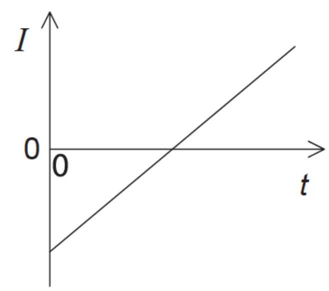
B.



C.



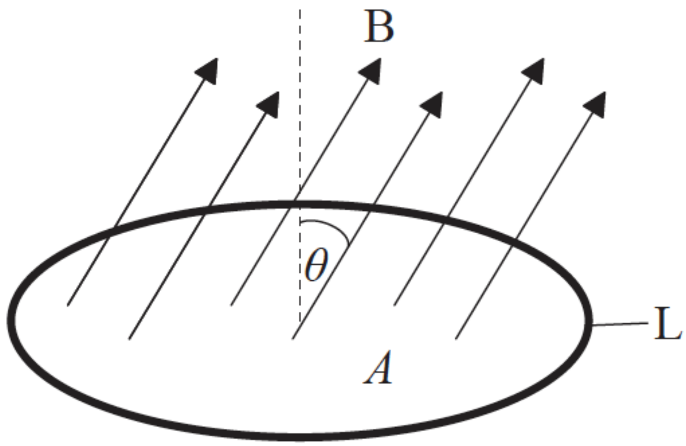
D.



Markscheme

A

4. The diagram shows a loop L of wire in a uniform magnetic field B. *[1 mark]*



The loop encloses an area *A* and the field is directed at an angle θ to the normal to the plane of the loop. The strength of B is increasing at a uniform rate *R*. What is the emf induced in L?

A. $\frac{RA}{\cos\theta}$

B. $RA\cos\theta$

C. $\frac{RA}{\sin\theta}$

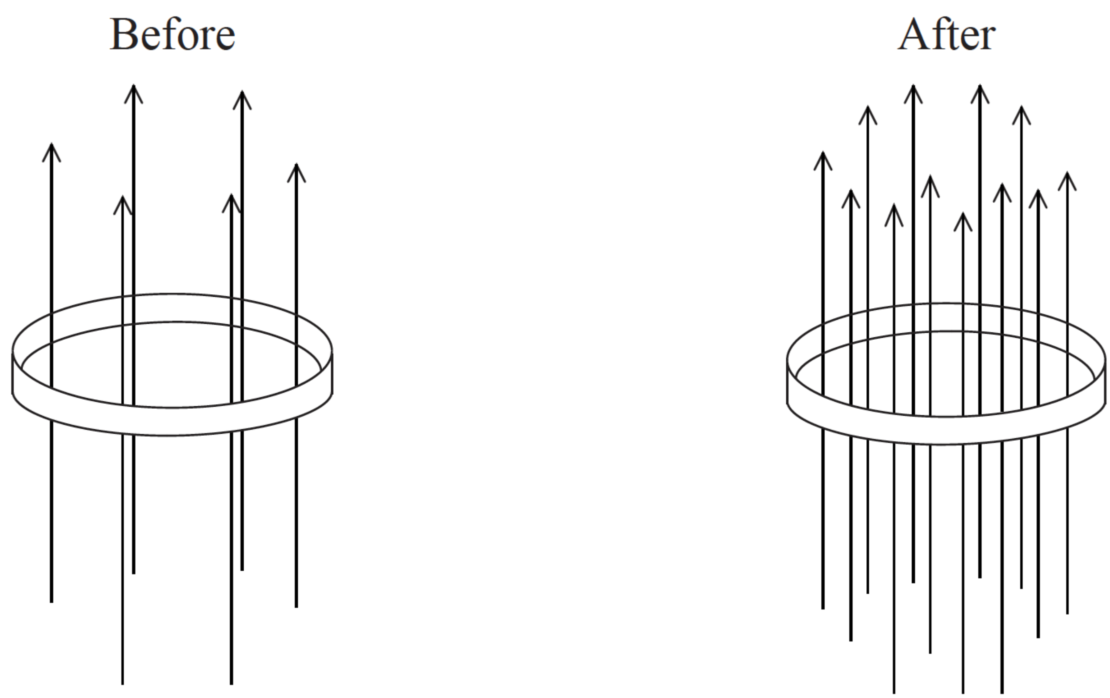
D. $RA\sin\theta$

Markscheme

B

This question is about electromagnetic induction.

A metal ring is placed in a magnetic field which is directed upwards. The magnetic flux through the ring increases over a time interval.



5a. State and explain the direction of the current induced in the ring during this change. *[3 marks]*

Markscheme

field caused by (induced) current must be downwards;
to oppose the change that produced it;
hence the current must be clockwise;

5b. The following data are available. *[3 marks]*

Resistance of ring = $3.0\times10^{-3}\Omega$
Initial magnetic flux = 1.2×10^{-5}Wb
Final magnetic flux = 2.4×10^{-5}Wb
Time interval = 2.0×10^{-3}s

Calculate the average current induced in the ring.

Markscheme

$\varepsilon = \left(\frac{\Delta\Phi}{\Delta t} =\right) \frac{2.4\times10^{-5}-1.2\times10^{-5}}{2.0\times10^{-3}}$ or 6.0×10^{-3}(v);

$I = \left(\frac{\varepsilon}{R} = \frac{6.0\times10^{-3}}{3.0\times10^{-3}} =\right) 2.0\,(\mathrm{A});$
*Award **[2]** for a bald correct answer.*

This question is about generating emfs.

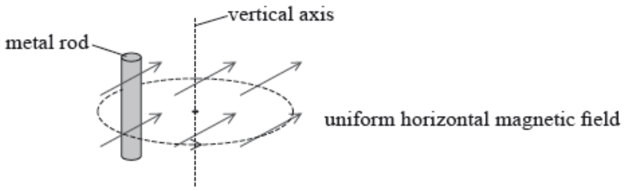
6a. Define *magnetic flux*. *[1 mark]*

Markscheme

magnetic flux density/magnetic field strength normal to a surface $\times$ area of surface;

Allow fully explained equation or diagram.

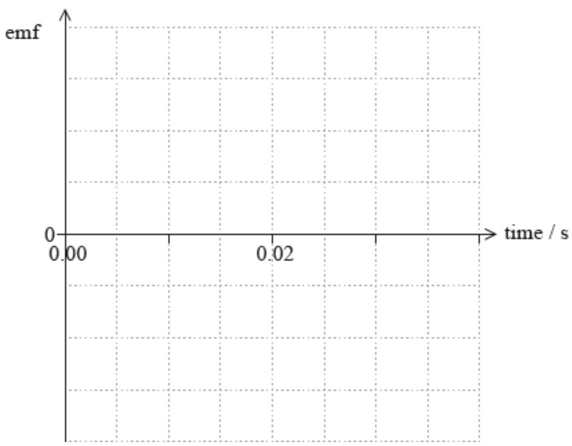
A vertical metal rod of length 0.25 m moves in a horizontal circle about a vertical axis in a uniform horizontal magnetic field.



The metal rod completes one circle of radius 0.060 m in 0.020 s in the magnetic field of strength 61 mT.

6b. (i) Determine the maximum emf induced between the ends of the metal rod. *[5 marks]*

(ii) Using the axes, sketch a graph to show the variation with time of the emf of the metal rod.



Markscheme

(i) $v = \frac{1}{0.02} \times 2\pi \times 0.06 \ \left(= 18.8 \, \text{m s}^{-1}\right)$;

$\varepsilon = (Blv =)\ 61 \times 10^{-3} \times 0.25 \times 18.8$;

290 (mV);

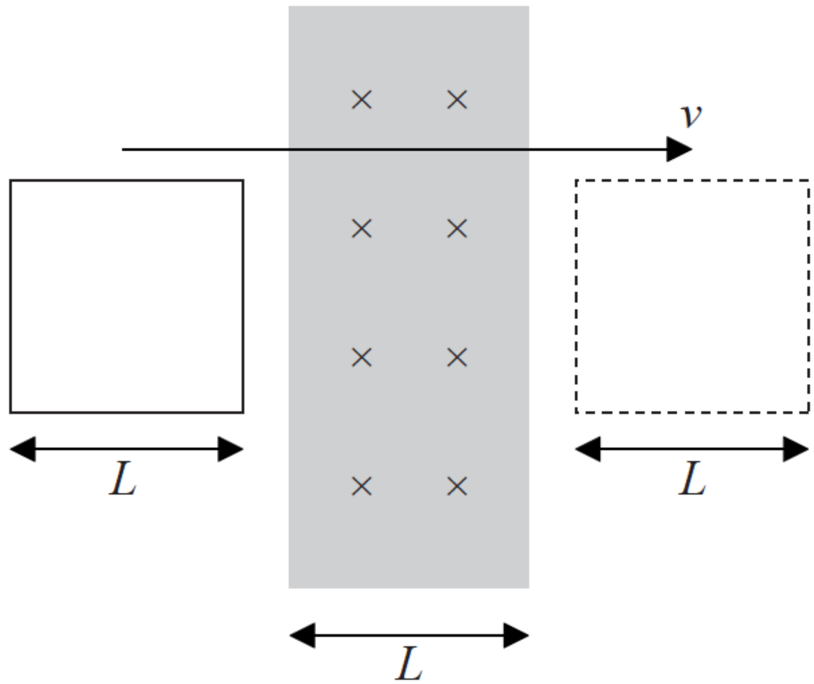
*Award **[3]** for a bald correct answer.*

(ii) sinusoidal curve drawn; *(at least half a cycle required)*

with a period of 0.02 s;

Accept any phase.

7. A uniform magnetic field directed into the page occupies a region of width *L*. A conducting coil of width *L* moves at constant speed *v*, from left to right, through the field. *[1 mark]*



From the instant that the coil enters the field until the instant that the coil leaves the field, which of the following best describes the direction of the current induced in the coil?

A. Anti-clockwise

B. Clockwise

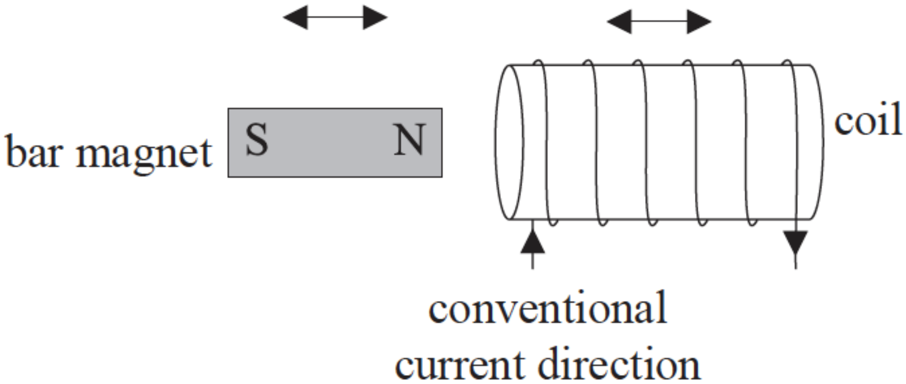
C. Anti-clockwise then clockwise

D. Clockwise then anti-clockwise

Markscheme

C

8. A coil and a magnet can move horizontally to the left or to the right at the same speed. *[1 mark]*



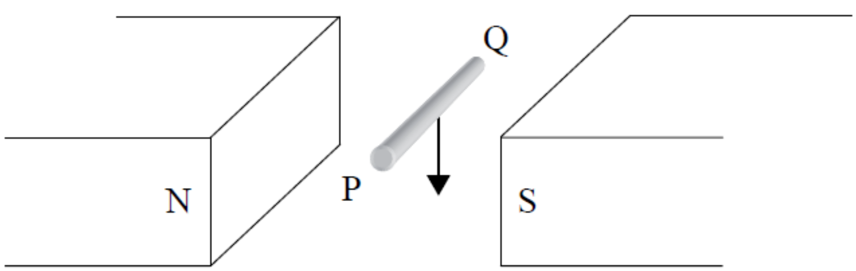
In which of the following will a conventional current be induced in the direction shown in the diagram when both the magnet and the coil are moving?

	direction of motion of magnet	direction of motion of coil
A.	to the left	to the right
B.	to the left	to the left
C.	to the right	to the right
D.	to the right	to the left

Markscheme

A

9. A length of copper wire PQ is moved downwards through the poles of two horizontal bar magnets as shown below. *[1 mark]*



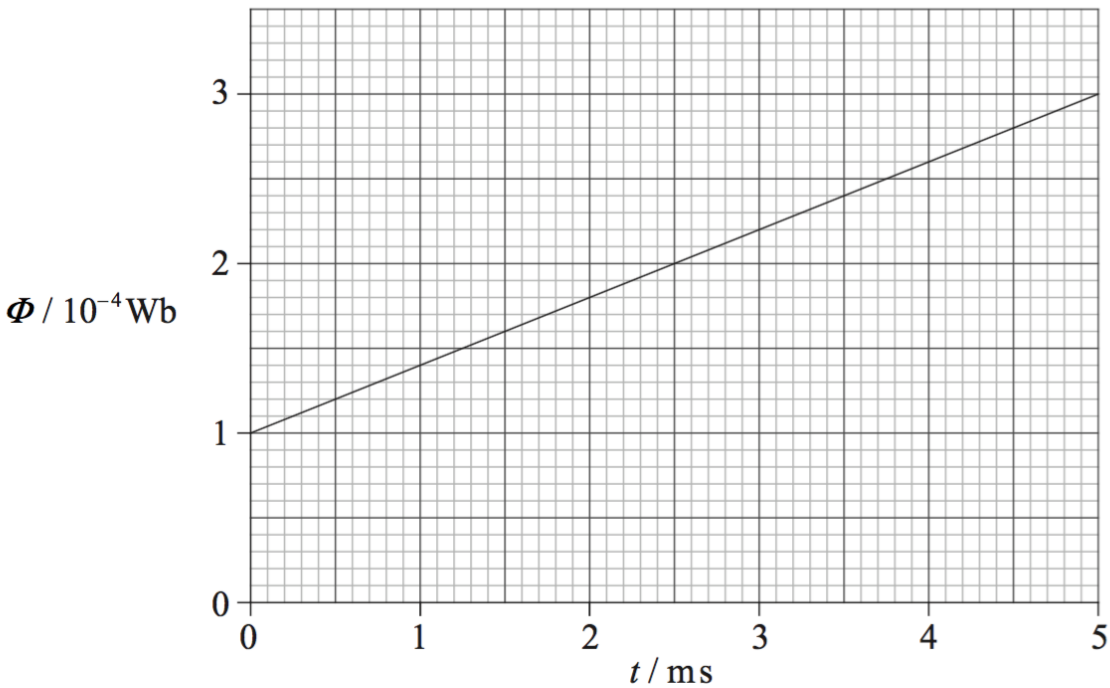
Compared to end Q, end P will have

A. fewer electrons.
B. more electrons.
C. fewer protons.
D. more protons.

Markscheme

A

10. The magnetic flux Φ through a coil with 1000 turns varies with time t as shown in the graph. *[1 mark]*



What is the magnitude of the emf produced in the coil?

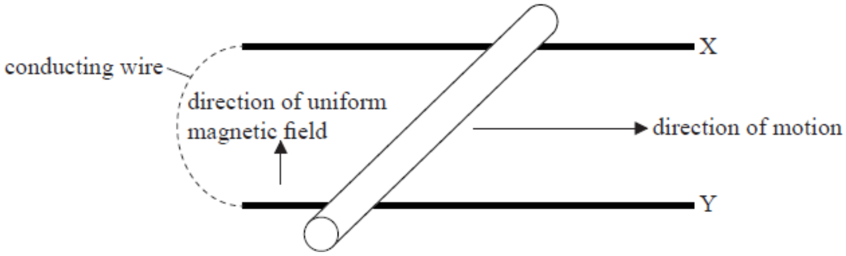
A. 0.04 V
B. 0.06 V
C. 40 V
D. 60 V

Markscheme

C

This question is about induced electromotive force (emf).

11a. A rod made of conducting material is in a region of uniform magnetic field. It is moved horizontally along two parallel conducting rails X and Y. The other ends of the rails are connected by a thin conducting wire. *[4 marks]*



The speed of the rod is constant and is also at right angles to the direction of the uniform magnetic field.

(i) Describe, with reference to the forces acting on the conduction electrons in the rod, how an emf is induced in the rod.

(ii) An induced emf is produced by a rate of change of flux. State what is meant by a rate of change of flux in this situation.

Markscheme

(i) electrons are moving at right angles to the magnetic field;
electrons experience a force directed along the rod / charge is separated in the rod;
the work done by this force to achieve this separation leads to an induced emf;

(ii) the product of magnitude of field strength and the rate at which the area is swept out by the rod is changing / the rate at which the rod cuts through field lines;

11b. The length of the rod in (a) is 1.2 m and its speed is 6.2 m s $^{-1}$. The induced emf is 15 mV. *[4 marks]*

(i) Determine the magnitude of the magnetic field strength through which the rod is moving.

(ii) Explain how Lenz's law relates to the situation described in (a).

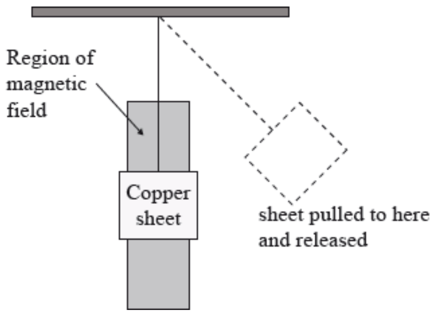
Markscheme

(i) $B = \frac{\varepsilon}{vl}$;
(must see the data book equation re-arranged or correctly aligning substitution with equation)

$= \left(\frac{15\times10^{-3}}{6.2\times1.2} =\right) 2.0\text{mT}$; *(accept 2+sf)*
*To award **[2]** both steps must be seen.*

(ii) Lenz's law states that the direction of the induced emf/current is such as to oppose the change producing it;
there is a current in the rod due to the induced emf;
the force on the current/rod due to the magnetic field is in the opposite direction to the force producing the motion of the rod;

12. A copper sheet is suspended in a region of uniform magnetic field by an insulating wire connected to a horizontal support. The sheet is pulled to one side so that it is outside the region of the field, and then released. *[1 mark]*



The uniform magnetic field is directed into the plane of the paper.

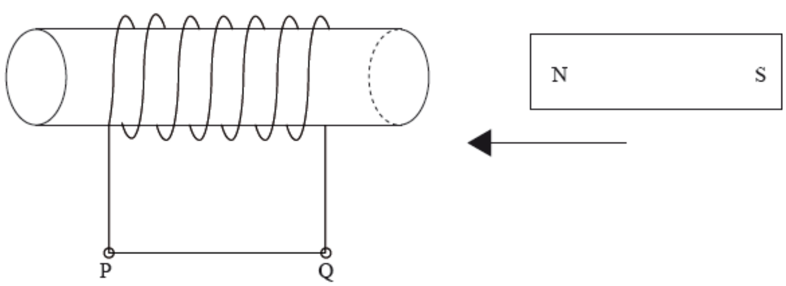
Which of the following is true for both the direction of the induced current in the sheet and the change in amplitude of the oscillations of the sheet with time?

	Direction of induced current	Change in amplitude
A.	stays the same	no change
B.	changes	decreases
C.	stays the same	decreases
D.	changes	no change

Markscheme

B

13. A permanent bar magnet is moved towards a coil of conducting wire wrapped around a non-conducting cylinder. The ends of the coil, P and Q are joined by a straight piece of wire. *[1 mark]*



The induced current in the **straight piece of wire** is

A. alternating.

B. zero.

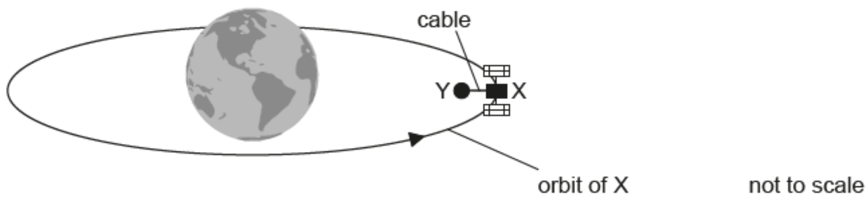
C. from P to Q.

D. from Q to P.

Markscheme

C

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



14a. Satellite X orbits 6600 km from the centre of the Earth. *[2 marks]*

Mass of the Earth = 6.0 x 10 ^{24} kg

Show that the orbital speed of satellite X is about 8 km s $^{-1}$.

Markscheme

«$v = \sqrt{\frac{GM_E}{r}}$» = $\sqrt{\frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{6600 \times 10^3}}$

7800 «m s^{-1}»

Full substitution required

Must see 2+ significant figures.

Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

14b. the orbital times for X and Y are different. *[1 mark]*

Markscheme

Y has smaller orbit/orbital speed is greater so time period is less

Allow answer from appropriate equation

Allow converse argument for X

14c. satellite Y requires a propulsion system. *[2 marks]*

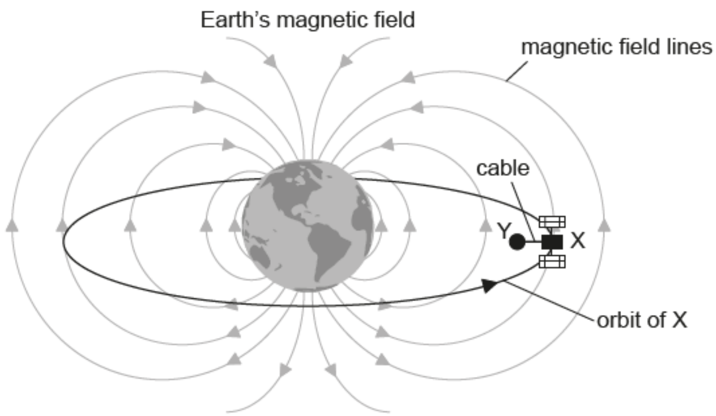
Markscheme

to stop Y from getting ahead

to remain stationary with respect to X

otherwise will add tension to cable/damage satellite/pull X out of its orbit

14d. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. *[3 marks]*



not to scale

Explain why satellite X becomes positively charged.

Markscheme

cable is a conductor and contains electrons

electrons/charges experience a force when moving in a magnetic field

use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive»

Alternative 2

cable is a conductor

so current will flow by induction flow when it moves through a B field

use of a suitable hand rule to show current to right so «X becomes positive»

Marks should be awarded from either one alternative or the other.

Do not allow discussion of positive charges moving towards X

14e. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. *[3 marks]*

Markscheme

electrons would build up at satellite Y/positive charge at X

preventing further charge flow

by electrostatic repulsion

unless a complete circuit exists

14f. The magnetic field strength of the Earth is 31 µT at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. *[2 marks]*

Markscheme

«$\varepsilon = Blv$ =» $31 \times 10^{-6} \times 7990 \times 15000$

3600 «V»

Allow 3700 «V» from $v = 8000$ m s^{-1}.

The cable acts as a spring. Satellite Y has a mass m of 3.5×10^{2} kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period T of 5.2 s.

14g. Estimate the value of k in the following expression. *[3 marks]*

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

Markscheme

use of k = «$\frac{4\pi^2 m}{T^2}$ =» $\frac{4\times\pi^2\times350}{5.2^2}$

510

N m^{-1} ***or*** kg s^{-2}

Allow MP1 and MP2 for a bald correct answer

Allow 500

Allow N/m etc.

14h. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. *[2 marks]*

Markscheme

E_p in the cable/system transfers to E_k of Y

and back again twice in each cycle

Exclusive use of gravitational potential energy negates MP1