Magnetic fields and forces on wires solutions

Electromagnetism 1 Testing a camera focusing actuator

Matching answers and examiner-style commentary

OCR A H556 | A-level physics | Module 6 | 45 marks

Specification points covered

6.3.1(a–d) Sources and patterns of magnetic fields; Fleming's left-hand rule.

6.3.1(e)(i–ii), (f) Force on a wire, measuring uniform flux density and the tesla.

Prior learning applied: resultant forces, Newton's third law, springs and uncertainty.

Use g = 9.81 m s^{-2}. The length symbol ℓ means wire length, not current I.

1 Read the actuator brief

A camera focuses by moving a lens horizontally. A voice coil in a permanent magnet's radial gap field pushes the lens against a return spring.

For actuator calculations, all active wire is perpendicular to the local field and its force contributions act along the lens axis. The total active length is 0.400 m. The nominal gap flux density is 0.180 T.

Positive drive current gives a rightward magnetic force on the lens coil.

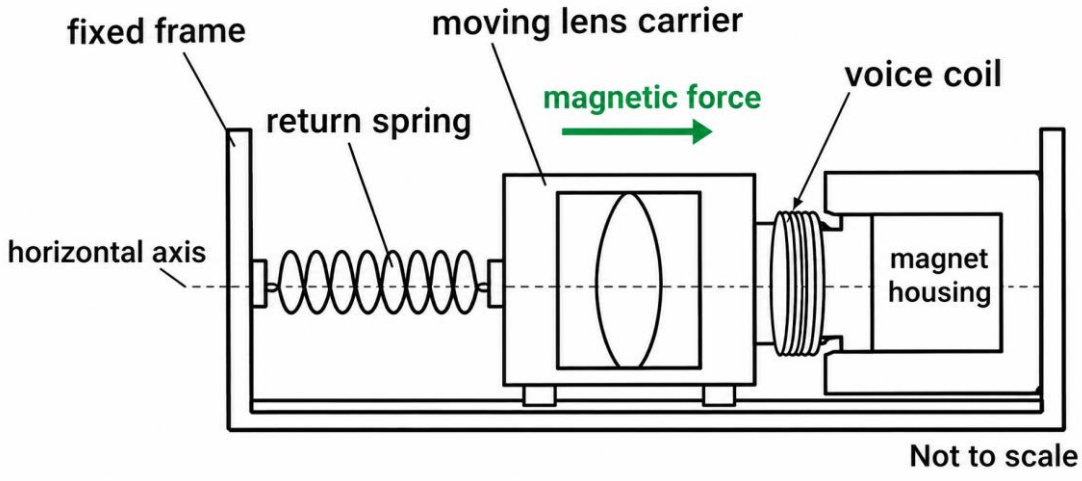


Figure 1 Horizontal focusing actuator

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1(a) A permanent magnet produces the actuator's gap field. What produces the magnetic field of its current-carrying coil? **[1 mark]**

The moving electric charges in the coil produce its magnetic field. A current is a flow of charge.

Marking guidance 1: moving charges/current.

1(b) Define magnetic flux density using a straight wire perpendicular to the field, and state its SI unit. **[2 marks]**

Magnetic flux density B is the force per unit current per unit length on a straight wire placed perpendicular to the field: $B = F/(I\ell)$.

The SI unit is the tesla, T; $1\ T = 1\ N\ A^{-1}\ m^{-1}$.

Marking guidance 1: complete operational definition or defined equation with perpendicular condition. 1: tesla/T.

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2 Map the fields and directions

2(a) Viewed end-on, the current in a long straight lead is into the page. Sketch at least three magnetic field lines. Show their direction and how the field becomes weaker farther from the lead. **[2 marks]**

Draw concentric circles centred on the wire. Arrows are clockwise when the conventional current is into the page.

Increase the spacing between successive circles with distance from the wire to represent the weaker field. Keep the circles clearly centred.

Marking guidance 1: concentric clockwise field lines. 1: clearly increasing separation with distance.

2(b) A separate flat circular coil has a horizontal axis. Its current is clockwise when viewed from the right. Sketch a side view of its magnetic field pattern, show the field direction through its centre, and label the right face N or S. **[3 marks]**

The right face is S: viewed from that side, clockwise conventional current gives a field into the coil.

In the side-view sketch, field lines pass approximately along the coil axis through its centre, from right to left. Outside, draw curved return paths from the left/N face towards the right/S face.

Magnetic field lines form closed loops. They do not start or end on the wire.

Marking guidance 1: recognisable axial/return-loop flat-coil pattern. 1: central field right to left. 1: right face S.

2(c) The actuator electronics also contain a long solenoid. Describe its field well inside the solenoid and near an end. State where a uniform-field model is the better approximation. **[2 marks]**

Well inside, field lines are approximately straight, parallel and equally spaced, giving a nearly uniform field along the axis.

Near an end the lines curve and spread; magnitude and direction vary. The central region is the better uniform-field approximation.

Marking guidance 1: central pattern linked to uniformity. 1: end spreading/non-uniformity and appropriate comparison.

2(d) In Figure 2 in Question 4, the gap field is from N to S and conventional current is out of the page. State the force direction on the wire. What happens to that force direction if only the current is reversed? **[2 marks]**

The field points right. Fleming’s left-hand rule gives an upward force on the wire for current out of the page.

Reversing current reverses the magnetic force: it acts downwards.

Marking guidance 1: upwards initially. 1: downwards after reversal.

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3 Use the magnetic force

3(a) Calculate the magnetic force on the actuator coil at a current of 0.150 A. **[1 mark]**

The supplied active length is perpendicular to the local field, so sin θ = 1.

F = Bℓℓ = (0.180)(0.150)(0.400) = 0.0108 N.

Marking guidance 1: 0.0108 N.

3(b) What actuator current is needed for a magnetic force of 0.0180 N at the nominal field? **[1 mark]**

Rearrange F = Bℓℓ because B and the active length are unchanged.

I = F/(Bℓ) = 0.0180/[(0.180)(0.400)] = 0.250 A.

Marking guidance 1: 0.250 A.

3(c) A separate straight wire has 50.0 mm in the same 0.180 T field and carries 0.800 A. The angle between the wire and the field is 30.0°. Calculate its magnetic force magnitude. **[2 marks]**

Use the angle between the current direction along the wire and B. Convert ℓ = 50.0 mm = 0.0500 m.

F = Bℓℓ sin θ = (0.180)(0.800)(0.0500) sin 30.0° = 3.60×10^{-3} N.

Marking guidance 1: correct active length and angular relationship. 1: 3.60×10^{-3} N.

3(d) The straight wire is turned parallel to B. State its force magnitude and explain. **[1 mark]**

The magnetic force is zero because θ = 0° or 180° and sin θ = 0.

Marking guidance 1: zero with the parallel/angle explanation.

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4 Calibrate the gap field

Figure 2 shows a fixed wire supported independently of the magnet. Only the magnet rests on the balance. The wire is perpendicular to the uniform field. The balance resolves 0.01 g.

Table 1 records changes relative to the zero-current reading. The active wire length stays 50.0 mm.

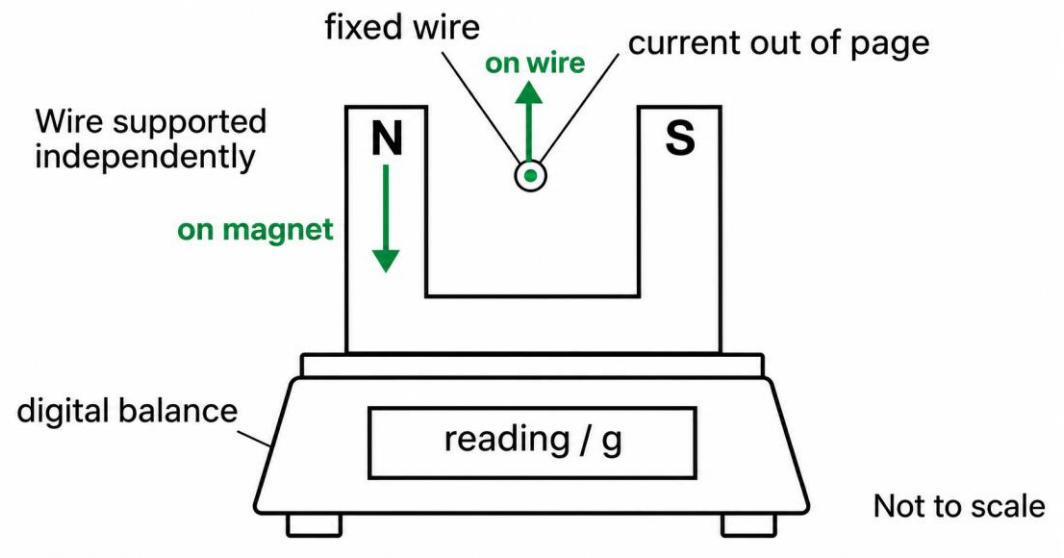


Figure 2 Separate wire and balance calibration

Table 1

I / A	Change in balance indication / g
0.00	0.00
0.20	0.18
0.40	0.37
0.60	0.55
0.80	0.73
1.00	0.92

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4(a) The balance indicates 142.60 g with current off and 143.33 g with current on. Calculate the magnetic force magnitude on the magnet. State its direction and the direction of the magnetic force on the wire. **[2 marks]**

The reading change is $\Delta m = 143.33 - 142.60 = 0.73\ g = 7.3 \times 10^{-4}$ kg. Use the change, not the full mass indication.

$F = \Delta mg = (7.3 \times 10^{-4})(9.81) = 7.161 \times 10^{-3}$ N $\approx 7.2 \times 10^{-3}$ N.

The balance indication increases, so the magnet receives an additional downward force. The equal-magnitude magnetic force on the separate wire is upwards.

Marking guidance 1: force from the converted reading difference. 1: magnet down and wire up.

4(b) For this reading the current is 0.800 A and the wire length in the uniform field is 50.0 mm. The wire is perpendicular to B. Calculate B. **[1 mark]**

$B = F/(I\ell) = (7.161 \times 10^{-3})/[(0.800)(0.0500)] = 0.179025$ T ≈ 0.179 T.

Marking guidance 1: about 0.179 T.

4(c) Use Table 1 to plot magnetic force magnitude against current in the blank space. Find B from a suitable line gradient. Show the coordinates used; use at least half the current range. **[3 marks]**

Convert each reading change from g to kg and multiply by g to obtain force. Plot F/N vertically and I/A horizontally; draw a sensible best-fit straight line.

For example, the end-to-end gradient is $[(0.92 \times 10^{-3})(9.81) - 0]/(1.00 - 0) = 9.0252 \times 10^{-3}$ N A^{-1}.

Since gradient = $B\ell$, $B = (9.0252 \times 10^{-3})/0.0500 = 0.180504$ T ≈ 0.181 T. A best-fit gradient should give about 0.180 T.

Marking guidance 1: correct axes, converted forces and suitable line. 1: meaningful large gradient triangle. 1: B near 0.180 T from gradient/0.0500; allow 0.177–0.185 T for a defensible graph.

4(d) For the single reading in 4(b), $I = (0.800 \pm 0.010)$ A and $\ell = (50.0 \pm 1.0)$ mm. Ignore balance uncertainty for this calculation. Estimate the absolute uncertainty in B and judge agreement with 0.180 T. **[3 marks]**

Step 1 B is obtained by dividing by both I and ℓ, so add their fractional uncertainties for this estimate.

$\Delta B/B = 0.010/0.800 + 1.0/50.0 = 0.0325 = 3.25\%$.

Step 2 Apply this fraction to the unrounded B value.

$\Delta B = (0.0325)(0.179025) = 0.005818$ T ≈ 0.006 T.

Report $B = (0.179 \pm 0.006)$ T. The interval includes 0.180 T, so the values agree within the stated uncertainty model. This does not prove all systematic effects are absent.

Marking guidance 1: fractional/percentage uncertainty combination. 1: about 0.006 T. 1: agreement judged using the interval.

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5 Evaluate a measurement

5(a) A technician writes: “Our value is close to 0.180 T, so the experiment is perfect. Repeating the readings will remove any constant zero offset.” Correct both claims. **[2 marks]**

Closeness alone is not sufficient: compare the difference with a justified uncertainty and consider systematic effects. Agreement does not make the experiment perfect.

Repeats can reduce the effect of random variation, but a constant zero offset remains in every reading. Measure/correct the offset or use a method that separates it.

Marking guidance 1: justified uncertainty/systematic-effect correction. 1: repeats do not remove constant offset.

5(b) Give two controls or improvements for the wire-and-balance experiment, explaining why each matters. **[2 marks]**

Keep the wire perpendicular to the field so sin θ stays at 1, and keep its measured active length within the uniform central gap.

Other justified choices include independent wire supports to avoid contact forces on the balance, repeated off/on zero checks, or limiting heating so the current and geometry remain stable.

Marking guidance 1 each: two specific choices with relevant reasons; accept equivalent valid controls.

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5 Evaluate a measurement Extended response

5(c) Write a coherent plan for checking the manufacturer's quoted B using the wire and balance. Explain how measurements lead to a value of B and how you would judge the claim. Include a graph and uncertainty approach; a sketch may support your answer. **[6 marks]**

Measure the length of straight wire actually in the central uniform gap. Support the wire separately, keep it perpendicular to the field, and place only the magnet on the balance. Record the zero-current balance indication.

Pass several measured currents through the wire. For each, record the change from a nearby zero-current reading and calculate $F = \Delta mg$ after converting g to kg. Repeat readings, check the zero and avoid excessive heating or movement.

Plot F against I. A straight-line gradient equals $B\ell$, so divide the gradient by the measured active length to obtain B. Use a large triangle on the fitted line rather than two nearby raw points.

Use measurement resolutions and the scatter or plausible limiting gradients to estimate uncertainty in B. Compare the manufacturer's value with the resulting interval and discuss any relevant systematic limitation. State a supported conclusion, rather than claiming accuracy from closeness alone.

Assessing 5(c) Best-fit marking guidance

Level 3 (5–6): a workable measurement method with geometry/zero controls AND a linked gradient-to-B analysis and uncertainty-based judgement The argument is clear, linked and scientifically sound.

Level 2 (3–4): a sound account of one strand with limited treatment of the other, or some relevant detail in both; links or evaluation are incomplete.

Level 1 (1–2): limited creditworthy method or analysis, presented as fragments with little connection. 0: no creditworthy response.

Use best fit, then the quality within the level. The exemplar is indicative, not a six-keyword checklist; accept other workable, justified approaches.

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6 Choose the actuator driver

The lens moves horizontally. Gravity and its supporting force act vertically and do not enter this horizontal balance. Spring force and friction oppose the required rightward motion.

6(a) The return spring has k = 5.00 N m^{-1}. At x = 3.00 mm, find the current needed to hold the lens stationary. Ignore friction for this holding calculation. **[1 mark]**

Stationary horizontal balance requires $BI\ell = kx$.

$I = kx/(B\ell) = (5.00)(0.00300)/[(0.180)(0.400)] = 0.2083\ A \approx 0.208\ A$.

Marking guidance 1: about 0.208 A.

6(b) At that displacement, the 8.00 g lens must accelerate rightwards at 0.500 m s^{-2}. Friction is 1.00 mN leftwards. Calculate the required magnetic force and current at the nominal B. **[3 marks]**

Step 1 The magnetic force must provide the resultant as well as oppose the spring and friction.

m = 8.00 g = 0.00800 kg; $F_{spring} = kx = (5.00)(0.00300) = 0.0150$ N.

$F_{mag} - 0.0150 - 0.00100 = (0.00800)(0.500)$.

$F_{mag} = 0.0200$ N.

Step 2 Convert that required magnetic force to current, not just the smaller resultant ma.

$I = 0.0200/[(0.180)(0.400)] = 0.2778\ A \approx 0.278\ A$.

Marking guidance 1: appropriate horizontal force balance with converted quantities. 1: 0.0200 N. 1: about 0.278 A.

6(c) Drivers can provide at most 0.250 A or 0.300 A. Choose a driver for 6(b), then check whether it still works if B is only 0.174 T. Take the other data as exact. **[3 marks]**

At nominal B the required current is 0.278 A, so the 0.250 A driver is insufficient and the 0.300 A driver is the candidate.

At the lower field, its maximum force is $F = (0.174)(0.300)(0.400) = 0.02088$ N.

This exceeds 0.0200 N, so the 0.300 A driver can still meet the requirement. Equivalently, the required weak-field current is $0.0200/[(0.174)(0.400)] = 0.2874\ A$, below 0.300 A.

Marking guidance 1: nominal choice against current limit. 1: correct weak-field force or current. 1: justified pass at the weak-field limit.

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6(d) A pupil says, “The wire and magnet exert equal and opposite magnetic forces, so neither can accelerate.” Explain the error. **[2 marks]**

Those forces act on different objects. They cannot be added as the force resultant on the lens/coil alone.

The lens accelerates when the forces acting on that lens/coil have a non-zero resultant. The magnet’s support supplies forces on the separate magnet.

Marking guidance 1: different objects. 1: resultant/acceleration for the chosen single object.

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