

|           |                                                                                |
|-----------|--------------------------------------------------------------------------------|
| 7(a)      | (induced) e.m.f. is (directly) proportional to rate                            |
|           | of change of (magnetic) flux (linkage)                                         |
| 7(b)(i)   | flux = e.m.f. $\times$ time                                                    |
|           | flux = $0.54 \times 15$                                                        |
|           | = $8.1 \text{ Wb}$                                                             |
| 7(b)(ii)  | $\Phi = BA$                                                                    |
|           | area = $8.1 / (38 \times 10^{-6})$                                             |
|           | = $2.1 \times 10^5 \text{ m}^2$                                                |
| 7(b)(iii) | area = speed $\times$ time $\times$ width                                      |
|           | $v = (2.1 \times 10^5) / (15 \times 68)$                                       |
|           | = $210 \text{ m s}^{-1}$                                                       |
| 7(b)(iv)  | opposing force (due to current in wings) must be backwards                     |
|           | from Fleming's left-hand rule, current (in wings) must be from Q to P          |
|           | current is from $-$ to $+$ inside an e.m.f. source so P is at higher potential |

|           |                                                                                                                                    |
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| 6(a)(i)   | $F = BIL$                                                                                                                          |
|           | force on QR = $5.2 \times 10^{-3} \times 1.2 \times 0.054 \times 190$                                                              |
|           | = $0.064 \text{ N}$                                                                                                                |
| 6(a)(ii)  | torque = force $\times$ perpendicular distance between forces                                                                      |
|           | = $0.064 \times 0.025 \cos \theta = (1.6 \times 10^{-3}) \cos \theta \text{ N m}$                                                  |
| 6(a)(iii) | one complete cycle of a sinusoidal curve between $0$ and $360^\circ$                                                               |
|           | $\tau$ axis labelled to show maximum and minimum torques at $\pm 1.6 \times 10^{-3} \text{ N m}$                                   |
|           | maximum at $0$ and $360^\circ$ and minimum at $180^\circ$ (or vice versa), with torque shown as zero at $90^\circ$ and $270^\circ$ |
| 6(b)      | (ferrous core) increases magnetic flux density                                                                                     |
|           | amplitude of torque increases                                                                                                      |

|                                               |                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-----------------------------------------------|---------------------------------------------------------|--|--|
| 1                                             | <b>Defining the problem</b>                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | vary $f$ and measure $V$ or $f$ is the independent variable and $V$ is the dependent variable                                                                                                                                                                                                 |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | keep $E$ <u>constant</u>                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | <b>Methods of data collection</b>                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | labelled diagram of workable experiment including: <ul style="list-style-type: none"><li>circuit with a.c. supply</li><li>oscilloscope connected in parallel with the resistor</li><li>workable circuit</li><li>oscilloscope and a.c. supply labelled</li></ul>                               |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | labelled signal generator or <u>variable frequency</u> power supply connected across the terminals                                                                                                                                                                                            |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | method to determine $V$ or $E$ from oscilloscope, e.g. multiply amplitude / height of wave by $y$ -gain on oscilloscope                                                                                                                                                                       |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | method to determine $f$ from oscilloscope, e.g. determine period $T$ by multiplying number of divisions in 1 cycle or horizontal distance in 1 cycle by the time base <b>and</b> $f = 1/T$                                                                                                    |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | <b>Method of Analysis</b>                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | plot a graph of $\frac{1}{V}$ against $f$ or equivalent, e.g. $f$ against $\frac{1}{V}$<br>Allow logarithms e.g. $\lg V$ against $\lg f$ .                                                                                                                                                    |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | relationship valid <u>if</u> a straight line is produced <u>passing through the origin</u><br>(for $\lg V$ against $\lg f$ relationship valid <u>if</u> a straight line is produced with <u>gradient = <math>-1</math></u> )                                                                  |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
| 1                                             | <table><tr><td><math>\frac{1}{V}</math> against <math>f</math></td><td><math>f</math> against <math>\frac{1}{V}</math></td></tr><tr><td><math>K = \frac{IES}{AN^2} \times \text{gradient}</math></td><td><math>K = \frac{IES}{AN^2} \times \frac{1}{\text{gradient}}</math></td></tr></table> | $\frac{1}{V}$ against $f$                                                                                                                                                                                                              | $f$ against $\frac{1}{V}$ | $K = \frac{IES}{AN^2} \times \text{gradient}$ | $K = \frac{IES}{AN^2} \times \frac{1}{\text{gradient}}$ |  |  |
| $\frac{1}{V}$ against $f$                     | $f$ against $\frac{1}{V}$                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
| $K = \frac{IES}{AN^2} \times \text{gradient}$ | $K = \frac{IES}{AN^2} \times \frac{1}{\text{gradient}}$                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | (for $\lg V$ against $\lg f$ : $K = \frac{EIS}{AN^2} \times 10^{-y\text{-intercept}}$ ).                                                                                                                                                                                                      |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | <b>Additional detail including safety considerations</b>                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | D1                                                                                                                                                                                                                                                                                            | precaution linked to <u>hot coil</u> or <u>hot resistor</u> or prevention of <u>burns</u> from <u>coil</u> or <u>resistor</u> , e.g. use gloves / switch off power supply when not measuring $V$ to prevent burns from coil / resistor |                           |                                               |                                                         |  |  |
|                                               | D2                                                                                                                                                                                                                                                                                            | keep $N$ <b>and</b> $A$ <b>and</b> $l$ <b>and</b> $S$ <u>constant</u>                                                                                                                                                                  |                           |                                               |                                                         |  |  |
|                                               | D3                                                                                                                                                                                                                                                                                            | method to keep $S$ constant, e.g. switch off power supply between readings to prevent heating of resistor or to allow resistor to cool                                                                                                 |                           |                                               |                                                         |  |  |
|                                               | D4                                                                                                                                                                                                                                                                                            | method to determine $A$ , e.g. use calipers / micrometer to measure diameter (of coil) / $d$ <b>and</b> $A = \frac{\pi d^2}{4}$                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | D5                                                                                                                                                                                                                                                                                            | repeat measurements of diameter $d$ along the length of the coil / in different directions <b>and</b> determine the average value of $d$                                                                                               |                           |                                               |                                                         |  |  |
|                                               | D6                                                                                                                                                                                                                                                                                            | method to determine the value of $S$ , e.g. separate circuit diagram showing resistor connected to ohmmeter, or circuit diagram showing resistor connected to a power supply with an ammeter and voltmeter <b>and</b> $S = V/I$        |                           |                                               |                                                         |  |  |
|                                               | D7                                                                                                                                                                                                                                                                                            | measure $l$ with a ruler / calipers                                                                                                                                                                                                    |                           |                                               |                                                         |  |  |
|                                               | D8                                                                                                                                                                                                                                                                                            | oscilloscope drawn connected across terminals / across signal generator <b>and</b> description to determine $E$                                                                                                                        |                           |                                               |                                                         |  |  |
|                                               | D9                                                                                                                                                                                                                                                                                            | adjust $y$ -gain for maximum amplitude<br><b>or</b><br>adjust time base for length of one wave or measure $n$ waves and divide measured time by $n$                                                                                    |                           |                                               |                                                         |  |  |
| 1                                             | D10                                                                                                                                                                                                                                                                                           | method to keep $E$ constant, e.g. check p.d. and alter supply<br><b>or</b><br>method to keep $l$ constant, e.g. tape coil<br><b>or</b><br>method to keep $A$ constant, e.g. wind wire on a cylinder                                    |                           |                                               |                                                         |  |  |

|                                                                                                          |                                                                                                                                                                                                                                                                                                                                                           |                                    |                           |                                                                                                                   |                                           |
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| 1                                                                                                        | <b>Defining the problem</b>                                                                                                                                                                                                                                                                                                                               |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Vary $p$ and measure $B$ OR $p$ is the independent variable and $B$ is the dependent variable.                                                                                                                                                                                                                                                            |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Keep $V$ <u>constant</u> or potential difference between the ends of each conductor <u>constant</u> .                                                                                                                                                                                                                                                     |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | <b>Methods of data collection</b>                                                                                                                                                                                                                                                                                                                         |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Labelled diagram of workable experiment including: <ul style="list-style-type: none"><li>conductors in parallel connected in series to power supply and resistor</li><li>circuit symbols for (variable) resistor and power supply</li><li>X labelled and one other label from L, P, Q, <math>p</math> and <math>q</math>.</li></ul>                       |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Voltmeter connected in parallel with conductors (to measure $V$ ) and conductors in parallel connected to a power supply.                                                                                                                                                                                                                                 |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Method to measure $L$ <b>and</b> $p$ <b>and</b> $q$ e.g. use a rule / ruler / calipers.                                                                                                                                                                                                                                                                   |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Method to measure $B$ , e.g. use a (calibrated) Hall probe <b>and</b> adjust / rotate probe until <u>maximum</u> value.                                                                                                                                                                                                                                   |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | <b>Method of Analysis</b>                                                                                                                                                                                                                                                                                                                                 |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | Plots a graph of $B$ against $\frac{1}{p}$ or equivalent.<br>Do not accept logarithms.                                                                                                                                                                                                                                                                    |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | <table><tr><td><math>B</math> against <math>\frac{1}{p}</math></td><td><math>\frac{1}{p}</math> against <math>B</math></td></tr><tr><td><math>Y = \frac{L \times \text{gradient}}{AV}</math></td><td><math>Y = \frac{L}{AV \times \text{gradient}}</math></td></tr></table>                                                                               | $B$ against $\frac{1}{p}$          | $\frac{1}{p}$ against $B$ | $Y = \frac{L \times \text{gradient}}{AV}$                                                                         | $Y = \frac{L}{AV \times \text{gradient}}$ |
| $B$ against $\frac{1}{p}$                                                                                | $\frac{1}{p}$ against $B$                                                                                                                                                                                                                                                                                                                                 |                                    |                           |                                                                                                                   |                                           |
| $Y = \frac{L \times \text{gradient}}{AV}$                                                                | $Y = \frac{L}{AV \times \text{gradient}}$                                                                                                                                                                                                                                                                                                                 |                                    |                           |                                                                                                                   |                                           |
| 1                                                                                                        | <table><tr><td><math>B</math> against <math>\frac{1}{p}</math></td><td><math>\frac{1}{p}</math> against <math>B</math></td></tr><tr><td><math>Z = \frac{q \times y\text{-intercept}}{\text{gradient}}</math><br/>OR<br/><math>Z = \frac{Lq \times y\text{-intercept}}{YAV}</math></td><td><math>Z = -q \times y\text{-intercept}</math></td></tr></table> | $B$ against $\frac{1}{p}$          | $\frac{1}{p}$ against $B$ | $Z = \frac{q \times y\text{-intercept}}{\text{gradient}}$<br>OR<br>$Z = \frac{Lq \times y\text{-intercept}}{YAV}$ | $Z = -q \times y\text{-intercept}$        |
|                                                                                                          | $B$ against $\frac{1}{p}$                                                                                                                                                                                                                                                                                                                                 | $\frac{1}{p}$ against $B$          |                           |                                                                                                                   |                                           |
|                                                                                                          | $Z = \frac{q \times y\text{-intercept}}{\text{gradient}}$<br>OR<br>$Z = \frac{Lq \times y\text{-intercept}}{YAV}$                                                                                                                                                                                                                                         | $Z = -q \times y\text{-intercept}$ |                           |                                                                                                                   |                                           |
|                                                                                                          | <b>Additional detail including safety considerations</b><br>Any <b>six</b> from:                                                                                                                                                                                                                                                                          |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D1 precaution linked to <u>high current</u> / <u>hot conductors</u> , e.g. use gloves / switch off power supply when not measuring $B$ / between measurements / allow conductors to cool                                                                                                                                                                  |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D2 keep $A$ <b>and</b> $L$ <b>and</b> $q$ constant                                                                                                                                                                                                                                                                                                        |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D3 use calipers / micrometer to measure diameter / $d$ of conductor <b>and</b> $A = \frac{\pi d^2}{4}$                                                                                                                                                                                                                                                    |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D4 repeat measurements of $d$ <u>in different positions</u> <b>and</b> <u>average</u> $d$                                                                                                                                                                                                                                                                 |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D5 method to determine the position of X in relation to the conductors, e.g. divide $L$ by two to find the midpoint of P / Q <b>and</b> use a set square / protractor / plumb line to mark X<br>OR<br>divide $L$ by two to find the midpoint of P / Q <b>and</b> use a grid to mark X                                                                     |                                    |                           |                                                                                                                   |                                           |
|                                                                                                          | D6 measure $B$ (using Hall probe) first in one direction and then in the opposite direction and average $B$<br>OR<br>Measure $B$ with current / p.d. in one direction and then in the opposite direction and average $B$                                                                                                                                  |                                    |                           |                                                                                                                   |                                           |
| D7 additional detail on measuring $p$ and / or $q$ , e.g. measure to the conductor and add on the radius |                                                                                                                                                                                                                                                                                                                                                           |                                    |                           |                                                                                                                   |                                           |

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| 1 | D8 description of method to keep $q$ constant, e.g. tape / adhesive putty to fix conductor Q to the bench OR for vertical methods fix conductor Q in clamp(s) attached to stand(s) to keep $q$ constant |
|   | D9 method to keep P and Q parallel, e.g. measure the separation (between the conductors) at different points                                                                                            |
|   | D10 relationship valid <u>if</u> a straight line is produced (with a y-intercept = $\frac{YZAV}{Lq}$ ).<br>Do not accept passing through the origin.                                                    |
|   | D11 method to keep $V$ constant, e.g. adjust / change variable resistor / power supply to keep voltmeter reading constant.                                                                              |