

**APhO 2025**  
**EXPERIMENTAL PROBLEM**  
**PHYSICS OF INDUCTION COOKING**

**Marking Scheme**

v. 3.0

| No  | Item | Answers                                                                                                                              | Partial Mark | Full Mark | Sum: Task Box | Sum: Section |
|-----|------|--------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------|---------------|--------------|
| 1.1 |      | Circuit diagram                                                                                                                      |              |           |               |              |
|     | a    | All circuits elements indicated with labels: VS, R, L, C                                                                             |              | 0.1       |               |              |
|     | b    | Recognition that $R_{TOT} = R_1 + R_c + R_L$                                                                                         |              | 0.1       |               |              |
|     | c    | Correct cable resistance. $R_c = (0.05 - 0.2) \text{ ohm}$ (0.15) + correct unit (0.05)                                              |              | 0.2       |               |              |
|     |      | Partially correct cable resistance. $R_c = (0.03 - 0.30) \text{ ohm}$                                                                | 0.1          |           | 0.4           |              |
| 1.2 |      | RLC resonance for $C=470\text{nF}$ and $2200 \text{ uF}$                                                                             |              |           |               |              |
|     | a    | Correct RLC data (f, VS and VR1 or I) with minimum 9 points for each C                                                               |              | 0.2x2     |               |              |
|     |      | Correct RLC data (f, VS and VR1 or I) with minimum 5 points for each C                                                               | 0.1 x 2      |           |               |              |
|     | b    | Correct resonance plot (labels (0.05), units (0.05), coverage >75% (0.1))                                                            |              | 0.2x2     |               |              |
|     | c    | Show resonance peak/impedance dip (for $C=2200\text{uF}$ peak is broad)                                                              |              | 0.1x2     |               |              |
|     | d    | Correct $L = (45 - 52) \text{ uH}$ for $C = 470 \text{ nF}$ , don't care for $2200 \text{ uF}$                                       |              | 0.2       |               |              |
|     |      | Partially correct $L = (14 - 141) \text{ uH}$ for $C = 470 \text{ nF}$                                                               | 0.1          |           | 1.2           |              |
| 1.3 | a    | Correct linear model of RLC impedance vs. frequency. Model can extract L and RL                                                      |              | 0.5       |               |              |
|     |      | Partially correct linear model with other R ( $R_1$ , $R_c$ or $R_L$ , or some combination) instead of $R_T$                         | 0.3          |           | 0.5           |              |
| 1.4 |      | Impedance analysis with linear model                                                                                                 |              |           |               |              |
|     | a    | RLC data (f, VS and VR1 or I) with minimum 9 points for each $C=470 \text{ uF}$ , $1000\text{uF}$                                    |              | 0.2x2     |               |              |
|     |      | RLC data (f, VS and VR1 or I) with minimum 5 points for each $C=470 \text{ uF}$ , $1000\text{uF}$                                    | 0.1x2        |           |               |              |
|     | b    | Correct data entries/analysis at least 5 for the linear model (y and x) for all 4 capacitors                                         |              | 0.1x4     |               |              |
|     | c    | Correct linear model plots for all 4 capacitors (labels (0.01), units (0.01), area coverage 75% (0.01), plot with valid data (0.12)) |              | 0.15x4    | 1.4           |              |
| 1.5 | a    | Correct L values (from 4 set) & its average (42 - 52 uH for each and average 0.1)                                                    |              | 0.5       |               |              |
|     |      | Partially correct L values (from 4 set) & its average (14 - 141 uH for each and average 0.05)                                        | 0.25         |           |               |              |
|     | b    | Correct RL values (from 4 set) & its average (0.4-0.7 ohm for each and average 0.1)                                                  |              | 0.5       |               |              |
|     |      | Partially correct RL values (from 4 set) & its average (0.2-0.9 ohm for each and average 0.05)                                       | 0.25         |           | 1.0           | 4.5          |
| 2.1 |      | Mutual induction circuit                                                                                                             |              |           |               |              |
|     | a    | Correct sketch (Vs, RLC one side, L and voltmeter on the other side)                                                                 |              | 0.4       |               |              |
|     |      | No C                                                                                                                                 | 0.2          |           | 0.4           |              |
| 2.2 |      | Mutual induction experiment with 2 configs                                                                                           |              |           |               |              |
|     | a    | Correct data for each configuration (min. 6 data points each)                                                                        |              | 0.3x2     |               |              |
|     |      | Partially correct data for each configuration (min. 3 data points each)                                                              | 0.15x2       |           |               |              |
|     | b    | Correct plot(axis, labels, data) (labels (0.01), units (0.01), coverage 75% (0.03), plot with valid data (0.15))                     |              | 0.2x2     | 1.0           |              |
| 2.3 | a    | Correct value of $M = (4 - 7) \text{ uH}$                                                                                            |              | 0.2x2     |               |              |
|     |      | Partially correct value of $M = (1.7 - 17) \text{ uH}$                                                                               | 0.1x2        |           | 0.4           |              |
| 2.4 |      | Skin depth experiment for determination of $n$ and sigma for 4 metals                                                                |              |           |               |              |
|     | a    | Correct linear equation between sec. coil voltage ( $\ln V_2$ ) vs. number of plates (N) (sol. eq. 9)                                |              | 0.2       |               |              |
|     |      | Exponential equation between sec. coil voltage (V) vs. number of plates (N)                                                          | 0.1          |           |               |              |
|     | b    | Correct linear equation model to extract n and sigma (sol. eq. 11)                                                                   |              | 0.2       |               |              |
|     | c    | Acceptable data for $V_2$ vs. no. of plates (N) and its analysis for each frequency (0.1 for each freq.)                             |              | 0.5x4     |               |              |

|            |          |                                                                                                                                                |          |       |            |            |
|------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------|----------|-------|------------|------------|
|            | <b>d</b> | Correct analysis to obtain delta vs frequency, min. 5 frequencies (0.1 for at least 2 frequencies, 0.1 for each additional freq.) for 4 plates |          | 0.4x4 |            |            |
|            | <b>e</b> | Plot of skin depth vs. freq. (labels (0.01), units (0.01), area coverage 75% (0.03), plot with valid data (0.15)) for 4 plates                 |          | 0.2x4 |            |            |
|            | <b>f</b> | Correct identification of the metal SS410 with invalid skin depth data                                                                         |          | 0.1   |            |            |
|            | <b>g</b> | Correct value of n for 3 metals (rounded to -1)                                                                                                |          | 0.2x3 |            |            |
|            |          | Partial correct value of n for 3 metals (rounded to -2)                                                                                        | 0.1x3    |       | <b>5.5</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>2.5</b> | <b>a</b> | Correct value of m (must be -1)                                                                                                                |          | 0.2   | <b>0.2</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>2.6</b> | <b>a</b> | Correct value of sigmas for 3 metals (+/-50% ref) (sigma Al = (1.9 -5.5)e7, sigma Cu = (2.9 - 8.8)e7, Sigma SS304 =(0.69-2.1)e6 S/m            |          | 0.2x3 |            |            |
|            |          | Partially correct value of sigmas for 3 metals (0.3 x - 3x ref) (sigma Al = (1.1 -11)e7, sigma Cu = (1.8 -18)e7, sigma SS304 =(0.4-4.1)e6 S/m  | 0.1x3    |       | <b>0.6</b> | <b>8.1</b> |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.1</b> | <b>a</b> | Correct diagram and labels for induction cooker (coil, current, magnetic field, metal plate, eddy current (each 0.04)                          | n x 0.04 | 0.2   | <b>0.2</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.2</b> | <b>a</b> | Correct power balance equation (Solution Eq. 17)                                                                                               |          | 0.2   |            |            |
|            |          | Partial, missing T0 term                                                                                                                       | 0.1      |       |            |            |
|            | <b>b</b> | Correct idea and obtain eq. to determine specific heat capacity (c)                                                                            |          | 0.3   | <b>0.5</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.3</b> |          | Aluminum specific heat (cooling experiment)                                                                                                    |          |       |            |            |
|            | <b>a</b> | Correct data (after transient, linear in T^4 vs dT/dt) for cooling experiment (time, RNTC, min. 10 data)                                       |          | 0.4   |            |            |
|            |          | Partially correct data for cooling experiment (time, RNTC, min. 5 data)                                                                        | 0.2      |       |            |            |
|            | <b>b</b> | Correct derivation of T as a function of RNTC (Solution Eq. 20)                                                                                |          | 0.1   |            |            |
|            | <b>c</b> | Correct data analysis (T, dT/dt, T^4) (min 10 data)                                                                                            |          | 0.5   |            |            |
|            |          | Partially correct data analysis (min 5 data)                                                                                                   | 0.3      |       |            |            |
|            | <b>d</b> | Correct plot e.g. T^4 vs. dT/dt (labels (0.02), units (0.02), area coverage 75% (0.06), plot with valid data (0.2))                            |          | 0.3   |            |            |
|            | <b>e</b> | Correct value of specific heat (c = 600 - 1200 J/kg K)                                                                                         |          | 0.2   |            |            |
|            |          | Partially correct value of specific heat (c = 270 - 2700 J/kg K)                                                                               | 0.1      |       | <b>1.5</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.4</b> |          | SS410 (cooling experiment)                                                                                                                     |          |       |            |            |
|            | <b>a</b> | Correct data (after transient, linear in T^4 vs dT/dt) for cooling experiment (time, RNTC, min. 10 data)                                       |          | 0.4   |            |            |
|            |          | Partially correct data for cooling experiment (time, RNTC, min. 5 data)                                                                        | 0.2      |       |            |            |
|            | <b>b</b> | Correct data analysis (T, dT/dt, T^4) (min 10 data)                                                                                            |          | 0.6   |            |            |
|            |          | Partially correct data analysis (min 5 data)                                                                                                   | 0.3      |       |            |            |
|            | <b>c</b> | Correct plot e.g. T^4 vs. dT/dt (labels (0.02), units (0.02), area coverage 75% (0.06), plot with valid data (0.2))                            |          | 0.3   |            |            |
|            | <b>d</b> | Correct value of specific heat (c = 320 - 600 J/kg K)                                                                                          |          | 0.2   |            |            |
|            |          | Partially correct value of specific heat (c = 140 - 1400 J/kg K)                                                                               | 0.1      |       | <b>1.5</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.5</b> |          | Heating experiment for Al pan                                                                                                                  |          |       |            |            |
|            | <b>a</b> | Correct theoretical model to solve for RLOAD (sol. Eq. 22)                                                                                     |          | 0.1   |            |            |
|            | <b>b</b> | Correct data in the "heating" experiment (RNTC vs time, min 7 data points for time) , repeated for 5 different current values                  |          | 0.1x5 |            |            |
|            | <b>c</b> | Correct data analysis (Power vs. Irms^2)                                                                                                       |          | 0.1x5 |            |            |
|            | <b>d</b> | Correct plot (Power vs. Irms^2) (labels (0.02), units (0.02), area coverage 75% (0.06), plot with valid data (0.2))                            |          | 0.3   |            |            |
|            | <b>e</b> | Correct value for RLOAD = 28 - 83 mOhm                                                                                                         |          | 0.2   |            |            |
|            |          | Partially correct value for RLOAD = 17 - 160 mOhm (only valid if less than for SS410)                                                          | 0.1      |       | <b>1.6</b> |            |
|            |          |                                                                                                                                                |          |       |            |            |
| <b>3.6</b> |          | Heating experiment for SS410 pan                                                                                                               |          |       |            |            |
|            | <b>a</b> | Correct data in the "heating" experiment (RNTC vs time, min 7 data points for time) , repeated for 5 different current values                  |          | 0.1x5 |            |            |
|            | <b>b</b> | Correct data analysis (Power vs. Irms^2)                                                                                                       |          | 0.1x5 |            |            |
|            | <b>c</b> | Correct plot (Power vs. Irms^2) (labels (0.02), units (0.02), coverage 75% (0.06), plot with valid data (0.2))                                 |          | 0.3   |            |            |
|            | <b>d</b> | Correct value for RLOAD = 70 - 210 mOhm                                                                                                        |          | 0.2   |            |            |
|            |          | Partially correct value for RLOAD = 41 - 410 mOhm (only valid if more than Al)                                                                 | 0.1      |       | <b>1.5</b> |            |

|     |   |                                                        |  |      |           |           |
|-----|---|--------------------------------------------------------|--|------|-----------|-----------|
|     |   |                                                        |  |      |           |           |
| 3.7 | a | Correct choice: (b)                                    |  | 0.1  | 0.1       |           |
|     |   |                                                        |  |      |           |           |
| 3.8 | a | Correct choice: (b)                                    |  | 0.1  | 0.1       |           |
|     |   |                                                        |  |      |           |           |
| 3.9 |   | Efficiency                                             |  |      |           |           |
|     | a | Correct equation                                       |  | 0.1  |           |           |
|     | b | Correct efficiency value for AI = 5 - 15%              |  | 0.15 |           |           |
|     |   | Partially correct efficiency value for AI = 3 - 30%    |  | 0.1  |           |           |
|     | c | Correct efficiency value for SS410 = 12 - 35%          |  | 0.15 |           |           |
|     |   | Partially correct efficiency value for SS410 = 7 - 70% |  | 0.1  | 0.4       | 7.4       |
|     |   |                                                        |  |      |           |           |
|     |   | <b>TOTAL SUM</b>                                       |  |      | <b>20</b> | <b>20</b> |