

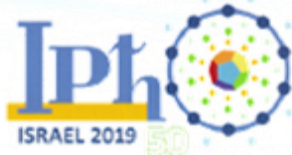
Wiedemann-Franz Law – Marking Scheme

Part A: Electric conductivity of metals (1.5 points)

| | | |
|-----|---|---------|
| A.1 | Measuring magnet fall (1.0 pts) | |
| | The number of total measurements : if $N \leq 15$ | 0.2 pts |
| | if $15 < N \leq 21$ | 0.5 pts |
| | if $N > 21$ | 0.7 pts |
| | Average travel time within 10% of solution for 2 out of 3 rods | 0.3 pts |
| A.2 | Calculation of conductivity (0.5 pts) | |
| | Correct calculation of conductivity from A1 | 0.1 pts |
| | Final result for 2 out of 3 values: Within 10% of correct value | 0.4 pts |
| | Within 20% of correct value | 0.2 pts |

Part B: Thermal conductivity of copper (3.0 points)

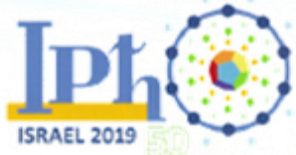
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|-----|---|---------|
| B.1 | Writing room temperature with units | 0.1 pts |
| B.2 | Design a 4-probe circuit (0.5 pts) | |
| | Drawing ammeter in series with source and heater | 0.2 pts |
| | Measuring voltage on heater and not power source | 0.3 pts |
| B.3 | Writing the equation for power and proper calculation | 0.1 pts |
| B.4 | Writing thermometers readings (0.5 pts) | |
| | Complete set (24 temperatures in table) | 0.2 pts |
| | Units | 0.1 pts |
| | 2 digits after decimal point | 0.1 pts |
| | Times within 1 minute of requirement (15,17.5,20 minutes) | 0.1 pts |
| B.5 | Thermal equilibrium graph (1.0 pts) | |
| | All 24 points are plotted | 0.4 pts |
| | Correct axes, with units | 0.2 pts |



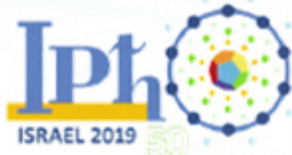
| | | |
|------|--|---------|
| | Points span on 1/2 the area of graph paper | 0.2 pts |
| | Slope is sketched for 17.5 min | 0.2 pts |
| B.6 | Obtaining κ_0 (0.5 points) | |
| | Correct expression for κ_0 | 0.1 pts |
| Op.1 | Range of κ_0 $[W / (mK)]$: $404 \leq \kappa_0 \leq 446$ | 0.2 pts |
| | $382 \leq \kappa_0 \leq 468$ | 0.1 pts |
| | Range of $\Delta T / \Delta t [K / s]$: $1.25 \cdot 10^{-3} \leq \Delta T / \Delta t \leq 1.55 \cdot 10^{-3}$ | 0.2 pts |
| | $1.1 \cdot 10^{-3} \leq \Delta T / \Delta t \leq 1.7 \cdot 10^{-3}$ | 0.1 pts |
| Op.2 | The value of the corrected κ (using the method in the solution) with κ_0 , $\Delta T / \Delta t$ and c_p, P_{loss} from the official solution is in range: | |
| | $376 \leq \kappa \leq 416$ | 0.4 |
| | $356 < \kappa < 376$ or $416 < \kappa < 436$ | 0.2 |
| B.7 | Correct answer - Higher value | 0.3 pts |

Part C: Heat loss and heat capacity of copper (4.0 points)

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|-----|--|---------|
| C.1 | Cooling-Heating-Cooling cycle (1.0 pts) | |
| | Number of measurement points for each step: if $3 \leq N < 5$ | 0.1 pts |
| | if $N \geq 5$ | 0.2 pts |
| | Heating step time in range $1[\text{min}] \leq t \leq 3[\text{min}]$ | 0.2 pts |
| | Cooling steps time $t > 200[s]$ | 0.2 pts |
| | If average between T4,T5 or average over all thermometers | 0.2 pts |
| | Used only T4 or only T5 | 0.1 pts |
| | The reported temperature mid-heating is: | |
| | Less than 2.5 [C] away from average temperature in B.4 | 0.2 pts |
| | Between 2.5[C] and 4.0[C] from average temperature in B.4 | 0.1 pts |



| | | |
|-----|---|---------|
| C.2 | Cooling – Heating – Cooling graph (1.0 pts) | |
| | Correct axes, units on axes | 0.2 pts |
| | Number of points on graph: $N \geq 15$ | 0.4 pts |
| | $12 \leq N < 15$ | 0.2 pts |
| | Points span on 1/2 the area of graph paper | 0.2 pts |
| | Slope lines are plotted for cooling steps | 0.2 pts |
| C.3 | Obtaining c_p and P_{loss} (1.0 pts) | |
| | $P_{loss} = c_p \cdot m \cdot \left. \frac{\partial T_{av}}{\partial t} \right _{Cooling}$ | 0.2 pts |
| | $P_{in} = c_p \cdot m \cdot \left(\left. \frac{\partial T_{av}}{\partial t} \right _{Heating} - \left. \frac{\partial T_{av}}{\partial t} \right _{Cooling} \right)$ or $P_{in} \cdot \Delta t = c_p \cdot m \cdot \Delta T$ | 0.4 pts |
| | Range of c_p in $[J / (kg \cdot K)]$: $425 \leq c_p \leq 350$ | 0.2 pts |
| | $465 \leq c_p \leq 310$ | 0.1 pts |
| | Range of P_{loss} in $[W]$: $0.25 \leq P_{loss} \leq 0.38$ | 0.2 pts |
| | $0.19 \leq P_{loss} \leq 0.44$ | 0.1 pts |
| C.4 | Correct κ (1.0 pts) | |
| | $c_p \cdot m \cdot \frac{\Delta T}{\Delta t}$ | 0.1 pts |
| | $c_p \cdot m \cdot \frac{\Delta T}{\Delta t}$ and P_{loss} are treated the same way | 0.1 pts |
| | Form of equation $\kappa = \frac{\kappa_0}{P} \left(P - \alpha \cdot \left(c_p \cdot m \cdot \frac{\Delta T}{\Delta t} + P_{loss} \right) \right)$ | 0.2 pts |
| | Writing that $\alpha = 0.5$ | 0.3 pts |
| | κ range in $[W / (mK)]$: $376 \leq \kappa \leq 416$ | 0.3 pts |
| | $356 < \kappa < 376$ or $416 < \kappa < 436$ | 0.2 pts |



Part D: Thermal conductivity of multiple metals (1.0 points)

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| D.1 | Writing temperature with units | 0.1 pts |
| D.2 | Temperature measurements (0.2 pts) | |
| | Measurement time is greater than 15 minutes | 0.1 pts |
| | Correct calculation of $\Delta T / \Delta x$ using 28mm spacing | 0.1 pts |
| D.3 | Calculation of κ for other metals (0.7 pts) | |
| | general form of $\kappa_{\alpha} = \kappa_{copper} \cdot \frac{Slope}{(\Delta T / \Delta x)_{\alpha}}$ | 0.1 pts |
| | Weighted average: 1:2 and 2:1 average between coppers (correct direction, see solution) | 0.4 pts |
| | Weighted average but wrong weights | 0.2 pts |
| | Slope from closest copper or simple average | 0.1 pts |
| | $103 [W / (mK)] \leq \kappa_{brass} \leq 126 [W / (mK)]$ | 0.1 pts |
| | $215 [W / (mK)] \leq \kappa_{Aluminum} \leq 263 [W / (mK)]$ | 0.1 pts |

Part E: The Wiedemann-Franz law (0.5 points)

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|-----|--|---------|
| E.1 | Wiedemann-Franz law table (0.5 pts) | |
| | Calculation of Lorenz number, using absolute temperature | 0.1 pts |
| | $2.12 [W\Omega / K^2] \leq L_{copper} \leq 2.39 [W\Omega / K^2]$ | 0.2 pts |
| | $2.13 [W\Omega / K^2] \leq L_{Brass} \leq 2.71 [W\Omega / K^2]$ | 0.1 pts |
| | $2.00 [W\Omega / K^2] \leq L_{Aluminum} \leq 2.54 [W\Omega / K^2]$ | 0.1 pts |

Please note that this marking scheme might change, particularly the ranges.