Question 4 (15 points)

(a) 2 point

For showing all four resistors in series with the battery.  
Note: One point was awarded for any number of resistors in series without a battery, or for the word "series" with no figure drawn.

(b) 2 points

For showing all four resistors in parallel with the battery.  
Note: One point was awarded for using any number of resistors in parallel without a battery, or for the word "parallel" with no figure drawn.

Note: No credit was given if there was a "short" in the circuit.

(c)

i. 4 points
The current in the 10-Ω resistor is the total current delivered by the battery. The other three resistors are in two parallel branches.  
For indicating that 50 Ω is in parallel to the 100 Ω resistor, OR for showing that the parallel combination must be added to the 10 Ω resistor  
Calculating the effective resistance of the parallel branches
For indicating that the wavelength or speed is less underwater:  
\[ \lambda = \frac{\lambda_0}{n} \text{ or } \nu = \frac{\nu_0}{n} \]

Combining this with the equation gives a compressed pattern.

\[ x \approx \frac{m \lambda L}{d} \]

For indicating that there will be a spreading of the pattern, or a larger central maximum in the pattern

For indicating that the new pattern is a one-slit diffraction pattern.

For indicating that the interference pattern will be compressed toward the central maximum

\[ x \approx \frac{m \lambda L}{d} \]

For referring to the equation , and indicating that as \( d \) increases the pattern is compressed

Note: Allowance was made in all calculations for small discrepancies in reading values from the graph.
Question 3

15 points total

(a) i.  3 points

For both a correct power formula and Ohm’s law, either shown explicitly or applied 1 point
For a correct calculation of resistance 1 point
For a correct calculation of current 1 point
   This point was awarded if an incorrect value for resistance was correctly used with 120 V.

The calculations can be done in slightly different ways and in different orders.
One example follows:

\[ P = IV \quad \text{and} \quad I = \frac{V}{R}, \quad \text{so} \quad P = \frac{V^2}{R} \]
\[ R = \frac{V^2}{P} = \frac{(120 \text{ V})^2}{30 \text{ W}} = 480 \Omega \]
\[ I = \frac{V}{R} = \frac{120 \text{ V}}{480 \Omega} = 0.25 \text{ A} \]

(a) ii.  2 points

For a correct calculation of resistance 1 point
For a correct calculation of current 1 point
   This point was awarded if an incorrect value for resistance was correctly used with 120 V.

Again, the calculations can be done in slightly different ways and in different orders.
One example follows:

\[ R = \frac{V^2}{P} = \frac{(120 \text{ V})^2}{40 \text{ W}} = 360 \Omega \]
\[ I = \frac{V}{R} = \frac{120 \text{ V}}{360 \Omega} = 0.33 \text{ A} \]

(b) i. and ii.  4 points

These two parts were scored as a unit.
For showing by calculation or by statement that the resistance in part (b)i is assumed 1 point
to be the same as in part (a)i, and the resistance in part (b)ii is assumed to be
the same as in part (a)ii
This point could also be awarded to students who recognized the bulbs as non-ohmic
and stated this clearly, specifying lower resistances to be used in the solution.
\[ R_{30^\circ} = 480 \Omega \]
\[ R_{40^\circ} = 360 \Omega \]
(b) i. and ii. continued

For adding both resistances to calculate the total series resistance \( R_{\text{tot}} \) used in the Ohm’s law calculation of current
\[
R_{\text{tot}} = 480 \, \Omega + 360 \, \Omega = 840 \, \Omega
\]
For calculating the correct current in part (b)i, or for a current consistent with the total resistance calculated
\[
I_{\text{30\degree}} = I_{\text{tot}} = \frac{V}{R_{\text{tot}}} = \frac{120 \, \text{V}}{840 \, \Omega} = 0.14 \, \text{A}
\]
For stating that the current in part (b)ii is the same as in part (b)i, whether or not the (b)i current is correct
\[
I_{\text{40\degree}} = I_{\text{30\degree}} = I_{\text{tot}} = 0.14 \, \text{A}
\]

(c) 3 points

2. 30 W bulb in the parallel circuit
1. 40 W bulb in the parallel circuit
3. 30 W bulb in the series circuit
4. 40 W bulb in the series circuit

For any order showing that both bulbs in parallel are brighter than both in series 1 point
For any order showing the 40 W bulb in the parallel circuit is brighter than the 30 W bulb in the parallel circuit 1 point
For any order showing the “30 W” bulb in the series circuit is brighter than the “40 W” bulb in the series circuit 1 point

(d) i. 1 point

For a correct answer or calculation consistent with values reported in part (a) 1 point
\[
P_{\text{tot}} = 30 \, \text{W} + 40 \, \text{W} = 70 \, \text{W}
\]
\[\text{OR} \quad P_{\text{tot}} = \frac{V^2}{R_{\text{tot}}} = \frac{(120 \, \text{V})^2}{206 \, \Omega} = 70 \, \text{W}\]
\[\text{OR} \quad P_{\text{tot}} = \sum VT = (120 \, \text{V})(0.25 \, \text{A}) + (120 \, \text{V})(0.33 \, \text{A}) = 70 \, \text{W}\]
(d) ii. 2 points

For using values from part (b) correctly in the equations
For correct answer or calculation consistent with values reported in part (b)

\[ P_{\text{tot}} = \frac{V^2}{R_{\text{tot}}} = \frac{(120 \, \text{V})^2}{840 \, \Omega} = 17 \, \text{W} \]

OR \[ P_{\text{tot}} = \sum I^2 R = (0.14 \, \text{A})^2 (480 \, \Omega) + (0.14 \, \text{A})^2 (360 \, \Omega) = 17 \, \text{W} \]

OR \[ P_{\text{tot}} = VI = (120 \, \text{V})(0.14 \, \text{A}) = 17 \, \text{W} \]

Note: Both points were awarded for the correct answer, 17 W, as long as it was consistent with the work in part (b). No points were awarded for answers of 70 W unless student’s work clearly showed that it was obtained using a combination of values for \( R \), \( V \), and \( I \) consistent with part (b).
1998 Q4

(a) 3 points

Draw your diagram in this box only.

For connecting bulbs A, B, and C end to end, in the correct order 1 point
For connecting bulb D in parallel across both B and C 1 point
For connecting the battery so that current exists in all four bulbs 1 point

(b) 3 points

For indicating that bulb A is brightest, and bulb D is brighter than both bulb B and C 1 point
For indicating that bulbs B and C have the same brightness 1 point
For correct justifications 1 point

For example, bulb A has the largest current through it, making it brightest. The voltage across bulb D is the same as that across bulbs B and C combined, so it is next brightest, leaving B and C as least bright. Bulbs B and C are in series, and thus have the same current through them, so they must be equally bright.
Question 4 (continued)

(c)

i. 2 points

- For indicating that the brightness of bulb $A$ decreases 1 point

- For a correct justification 1 point
  - For example: The total resistance of the circuit increases, so the current in bulb $A$ decreases

ii. 2 points

- For indicating that the brightness of bulb $B$ increases 1 point

- For a correct justification 1 point
  - For example: The current in bulb $B$ increases, or the voltage across it increases
1980 Q2

1980 B-2

(a) 7 points
The resistance of the device in proper operation is found from Ohm's law

\[ V = IR \]

so \[ R_{\text{device}} = \frac{V}{I} = \frac{12 \text{ volts}}{2 \text{ amperes}} = 6 \text{ ohms} \]

1 point

The required total resistance is

\[ R_{\text{total}} = \frac{E}{I} = \frac{24 \text{ volts}}{2 \text{ amperes}} = 12 \text{ ohms} \]

1 point

To obtain the additional 6 ohms resistance, place two 3-ohm resistors in series with the device.

2 points

The diagram is thus

![Diagram](image)

(Full credit was given for any equivalent circuit.)

(b) 3 points
Since the device requires only 2 amperes, a resistance in parallel with it must carry a current of

\[ 6 - 2 = 4 \text{ amperes} \]

The required resistance in parallel is

\[ R = \frac{12 \text{ volts}}{4 \text{ amperes}} = 3 \text{ ohms} \]

1 point

Thus, a single 3-ohm resistor in parallel will suffice, and the circuit diagram is

![Diagram](image)

(Again, full credit was given for any equivalent circuit.)

(c) 5 points
The power dissipated in a resistor is

\[ P = VI \quad \text{or} \quad P = I^2R \]

2 points

The current is \( I = 4 \) amperes

1 point

Thus, \( P = (12 \text{ V})(4 \text{ A}) = 48 \text{ watts} \)

or \( P = (4 \text{ A})^2(3 \Omega) = 48 \text{ watts} \)

2 points

Total 15 points
1982 Q4

4. a) 5 points
Since the clock requires the full 15 volts, it must be connected directly between A and B.
Since the radio requires less than 15 volts, there must be a resistance in series with it.
Using the conventional symbol for a resistor, the diagram becomes

![Circuit Diagram]

b) 5 points
Current and voltage through the resistor are related by Ohm's Law, \( V = IR \).
The current is \( I = 10 \) milliamperes.
Since the resistor and clock are in series,
\[
V_{\text{resistor}} = V_{\text{battery}} - V_{\text{radio}}
\]
\[
= 15 - 9 = 6 \text{ volts}
\]
Hence \( R = \frac{6 \text{ volts}}{10^{-1} \text{ amperes}} = 600 \text{ ohms} \)

Solution

Distribution of Points

1 point

1 point

1 point

2 points

c) 5 points
The power supplied by the battery is given by \( P = IV \)
where \( V = 15 \) volts
and \( I = 10 + 20 = 30 \text{ mA} \)
So the power is \( 15 \cdot 3 \times 10^{-2} = 0.45 \text{ watts} \)
The energy that must be supplied is the product of power and time,
\[
Pt = (0.45)(60) = 27 \text{ joules}
\]

Total 15 points
1983 Q3

3. (a) 5 points
   The total emf $\mathcal{E}$, current $I$, and total resistance $R_T$ are related by
   $$\mathcal{E} = IR_T$$
   1 point
   Since the batteries oppose one another, the total emf is $20 - 2 = 18$ volts
   1 point
   The equivalent resistance for the two parallel resistors is given by
   $$\frac{1}{r} = \frac{1}{6} + \frac{1}{12} = \frac{1}{4}$$
   so $r = 4$ ohms 1 point
   Since $R$ is in series with the pair, $R_T = 4 + R$
   1 point
   Therefore $R = R_T - 4 = \frac{18}{2} - 4 = 5$ ohms 1 point

(b) 3 points
   By Kirchhoff’s current law, $i_1 + i_2 = 2$ A 1 point
   Because the voltages are equal across the two resistors, $6i_1 = 12i_2$
   1 point
   Solving simultaneously gives
   $i_1 = \frac{4}{3}$ A 1 point
   $i_2 = \frac{2}{3}$ A

(c) 4 points
   The potential drop between $B$ and $X$ is across resistor $R$, so
   $$V_B = (2 \text{ A}) (5 \Omega) = 10 \text{ volts}$$
   1 point
   The potential at $C$ is 20 volts lower than at $B$
   $$V_C = 10 - 20 = -10 \text{ volts}$$
   1 point
   Point $D$ is 2 volts more negative than $X$
   $$V_D = -2 \text{ volts}$$
   1 point
   For having all 3 signs correct 1 point

(d) 3 points
   The power supplied by a battery is
   $$P = \mathcal{E}I$$
   1 point
   Substituting given values
   $$P = (20 \text{ V}) (2 \text{ A}) = 40 \text{ watts}$$
   2 points
1990 Q3

1990 Physics B

3.

(a) 3 points
For recognizing that 4 Ω and 8 Ω resistors are in series
4 Ω + 8 Ω = 12 Ω
1 point
For recognizing that the 12 Ω resistor is in parallel with
the other two resistors
\[
\frac{1}{12 \, \Omega} + \frac{1}{12 \, \Omega} = \frac{1}{6 \, \Omega}
\]
Equivalent resistance \( R_{eq} = 6 \, \Omega \)
1 point

(b) 3 points
For calculating the total resistance of the circuit:
5 Ω + 1 Ω + 6 Ω = 12 Ω
1 point
\( I = \frac{V}{R} \) (or equivalent)
1 point
\( I = \frac{24 \, V}{12 \, \Omega} = 2 \, A \)
1 point

(c) 2 points
For recognizing that there is a voltage drop due to the
internal resistance of the battery.
1 point
\[
V_{AC} = V - IR_{internal}
= 24 \, V - (2 \, A)(1 \, \Omega) = 22 \, V
\]
1 point

(d) 3 points
\( P = I^2R \)
1 point
For recognizing that the current is divided evenly between
both of the parallel branches
1 point
\( P = (1 \, A)^2(12 \, \Omega) = 12 \, W \)
1 point

Alternate Solution

(Alternate Points)
\( P = \frac{V^2}{R} \)
(1 point)
\( V = 22 \, V - (2 \, A)(5 \, \Omega) = 22 \, V - 10 \, V = 12 \, V \)
(1 point)
\( P = \frac{(12 \, V)^2}{12 \, \Omega} = 12 \, W \)
(1 point)

(e) 1 point
\( V_{BC} = IR = (2 \, A)(6 \, \Omega) \) or \( (1 \, A)(12 \, \Omega) = 12 \, V \)
1 point
1990 Physics B

(f) 2 points

\[ P = \frac{V^2}{R} \]

For recognizing that the external battery voltage, \( V = 22 \text{ V} \), should be used.

\[ P = \frac{(22 \text{ V})^2}{11 \text{ } \Omega} = 44 \text{ } \Omega \]

(full credit also given for other equivalent correct solutions)

For three or more answers with correct units, and no incorrect units 1 point
1987 Q4

4.

(a) 4 points
Solution for resistance $R_\parallel$ of parallel network

$$\frac{1}{R_\parallel} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{4} + \frac{1}{12}$$

1 point

$$R_\parallel = 3 \, \Omega$$

1 point

Total resistance $R_{tot}$ is given by

$$R_{tot} = R_\parallel + R_3 = 3 + 9$$

1 point

$$R_{tot} = 12 \, \Omega$$

(b) 2 points

$$\xi = iR_{tot}$$

1 point

$$\xi = (0.4)(12) = 4.8 \, V$$

1 point

(c) 2 points

$$V_1 = iR_\parallel$$

1 point

$$V_1 = (0.4)(3) = 1.2 \, V$$

1 point

Any correct alternate method received full credit.

(d) 2 points

$$P = i^2R \text{ (or } P = \frac{V^2}{R} \text{ or } P = iV)$$

1 point

$$P = \left( \frac{1.2}{4} \right)^2 (4) = \left( .3 \right)^2 (4) = 0.36 \, W$$

1 point

(this point awarded also for correct substitutions in either of the alternate equations above)

(e) 2 points

$$Q = it$$

1 point

$$Q = (0.4)(60) = 24 \, C$$

1 point

Extra 3 points

For correct units on all answers, (a) through (e) 3 points
(l 1 point awarded for one correct unit, and 2 points awarded for 2, 3, or 4 correct units)
1981 Q4

Solution

4. Preliminaries, 7 points
(Necessary in order to answer a, b, or c)
The resistance \( R_p \) of the parallel combination of three resistors is given by

\[
\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}, \quad \text{so}
\]

\[
\frac{1}{R_p} = \frac{1}{4} + \frac{1}{4} + \frac{1}{2} = 1, \quad \text{and}
\]

\( R_p = 1 \text{ ohm} \)

The two batteries are connected with opposing emfs, so the total emf in the circuit is

\( \mathcal{E} = 60 - 12 = 48 \text{ volts} \)

The total resistance in the circuit is the sum of all the resistances in series:

\( R = 3\Omega + 3\Omega + 1\Omega + 1\Omega = 8\Omega \)

The total current in the circuit is given by Ohm's law as

\( I = \frac{\mathcal{E}}{R} = \frac{48}{8} = 6 \text{ amperes} \)

a) 2 points

The voltage across the parallel combination is

\( V = IR_p = 6 \cdot 1 = 6 \text{ volts} \)

so the current through the 2-ohm resistor is

\( I_2 = \frac{6}{2} = 3 \text{ amperes} \)

Alternate method:

The current through the parallel resistors divides in inverse proportion to the resistance, so

\( I_2 = 6 \text{ amperes} \cdot \frac{\frac{1}{4}}{\frac{1}{4} + \frac{1}{4} + \frac{1}{4}} = 3 \text{ amperes} \)

b) 3 points

Power dissipated in a resistor is

\( P = I^2R \)

The current in the 3-ohm resistor is \( I = 6 \text{ amperes} \), so

\( P = 6^2 \cdot 3 = 108 \text{ watts} \)

c) 3 points

The terminal voltage of the battery is found by combining the emf \( \mathcal{E} \) and the potential drop \( Ir \) across the internal resistance.

Here, the battery is being charged up, with current in the battery from positive to negative, so

these terms must be added; that is, \( V_s = \mathcal{E} + \sum I_r \)

Therefore, \( V = 12 + 6 \cdot 1 = 18 \text{ volts} \)

Total 15 points
1989 Q3

3. (a)
   i. 2 points
      \[ P = I^2R \text{ or equivalent} \]  
      \[ P = (2\text{ A})^2(10\ \Omega) = 40\ \text{W} \]  
      1 point
      1 point
   
   ii. 3 points
      \[ P_{\text{motor}} = P_m - Fv \text{ or equivalent} \]  
      1 point
      For any explicit or implicit use of \( F = mg \)  
      1 point
      \[ P_m = (1\ \text{kg})(9.8\ \text{m/s}^2)(2\ \text{m/s}) \]  
      \[ P_m = (1\ \text{kg})(10\ \text{m/s}^2)(2\ \text{m/s}) \]  
      \[ P_m = 19.6\ \text{W} \text{ or } 20\ \text{W} \]  
      1 point
   
   iii. 2 points
      For an indication of summing the previous two answers:
      \[ P_{\text{batt}} = P_m + P_R \]  
      1 point
      \[ P_{\text{batt}} = 40\ \text{W} + 19.6\ \text{W} \text{ or } P_{\text{batt}} = 40\ \text{W} + 20\ \text{W} \]  
      \[ P_{\text{batt}} = 59.6\ \text{W} \text{ or } 60\ \text{W} \]  
      1 point
   
(b)
   i. 2 points
      \[ V = IR \]  
      \[ V = (2\ \text{A})(10\ \Omega) = 20\ \text{V} \]  
      1 point
      1 point
      
      **Alternate solution**
      \[ P = IV_R \]  
      (Alternate points)
      \[ (1\ \text{point}) \]  
      \[ V_R = \frac{P}{I} = \frac{40\ \text{W}}{2\ \text{A}} = 20\ \text{V} \]  
      (1 point)
   
   ii. 2 points
      \[ V_{\text{motor}} = V_m = \frac{P}{I} \]  
      1 point
      \[ V_m = \frac{19.6\ \text{W}}{2\ \text{A}} = 9.8\ \text{V} \text{ or } V_m = \frac{20\ \text{W}}{2\ \text{A}} = 10\ \text{V} \]  
      1 point
   
   iii. 1 point
      \[ V_{\text{batt}} = V_R + V_m \]  
      \[ V_{\text{batt}} = 20\ \text{V} + 9.8\ \text{V} = 29.8\ \text{V} \text{ or } V_{\text{batt}} = 20\ \text{V} + 10\ \text{V} = 30\ \text{V} \]  
      1 point
      
      **Alternate solution**
      \[ V_{\text{batt}} = P/I \]  
      (Alternate points)
      \[ V_{\text{batt}} = \frac{59.6\ \text{W}}{2\ \text{A}} = 29.8\ \text{V} \text{ or } V_{\text{batt}} = \frac{60\ \text{W}}{2\ \text{A}} = 30\ \text{V} \]  
      (1 point)
3. (continued)
(c) 1 point
\[ V_m = (2 \text{ m/s})k, \quad V_m' = (3 \text{ m/s})k, \text{ where } k \text{ is a constant} \]
\[ \frac{V_m'}{V_m} = \frac{3}{2} \]
\[ V_m' = \frac{3}{2} V_m = 14.7 \text{ V or 15 V} \]

1 point

(d) 1 point
\[ V_R' = V_{\text{batt}} - V_m' \]
\[ = 29.8 \text{ V} - 14.7 \text{ V or 30 V} - 15 \text{ V} \]
\[ = 15.1 \text{ V or 15 V} \]
\[ R' = \frac{V_R'}{I} = \frac{V_R'}{2 \text{ A}} = 7.55 \Omega \text{ or 7.5 } \Omega \]

1 point

Additional 1 point awarded for correct use of units
1991 Q4

4. (a) & (b) 6 points

For any attempt to relate \( V_{xy} \), \( \xi \), and \( Ir \) linearly 1 point

For a correct relationship: \( V_{xy} = \xi - Ir \) 1 point

For correctly substituting data from the graph 1 point

e.g.: 4 V = \( \xi \) - (1 A)r
3 V = \( \xi \) - (3 A)r

For an attempt to solve the simultaneous equations 1 point

\[
\begin{align*}
4 \text{ V} &- 3 \text{ V} = r(-1 \text{ A} + 3 \text{ A}) \\
1 \text{ V} &- r(2 \text{ A}) \\
r &- 0.5 \Omega \\
4 \text{ V} &- \xi - (1 \text{ A})(0.5 \Omega) = \xi - 0.5 \text{ V} \\
\xi &- 4.5 \text{ V}
\end{align*}
\]

(Alternate Solution) (Alternate Points)

(a) (3 points)

For extending the graph 1 point

For identifying the y-intercept with the emf 1 point

For correct value: \( \xi = 4.5 \text{ V} \) 1 point

(This last point was awarded for any reasonable answer corroborated by a student’s drawing on the graph)

(b) (3 points)

For indicating that \( r \) is equal to the (negative) slope of the graph 1 point

For the correct absolute value of \( r \) 1 point

For a positive value: \( r = 0.5 \Omega \) 1 point

(c) 3 points

For an expression of Ohm's Law:
\( V_{xy} = IR \) or \( \xi = I(R + r) \) 1 point

For correct substitution:
3 V = (3 A) (R) or 4.5 V = (3 A) (R + 0.5 \Omega) 1 point

\( R = 1 \Omega \) 1 point
4. (continued)

(d) 3 points
For an indication that $I_{\text{max}}$ occurs for $R = 0$ or $V_{xy} = 0$ 1 point

$I_{\text{max}} = \frac{\varepsilon}{r}$

For correct substitution:

$I_{\text{max}} = 4.5 \text{ V}$ 1 point

$I_{\text{max}} = 0.5 \text{ \Omega}$ 1 point

$I_{\text{max}} = 9 \text{ A}$ 1 point

(Alternate Solution) (Alternate Points)

For indicating that the x-intercept gives $I_{\text{max}}$ 1 point

For extrapolation to answer:

$I_{\text{max}} = 9 \text{ A}$ 2 points

(These last points were awarded for any reasonable answer corroborated by a student’s drawing on the graph)

(e) 3 points

For placing the ammeter in series with $R$ 1 point

For placing voltmeter in parallel with $R$ 1 point

For a correct circuit for both meters 1 point
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**Question 5**

10 points total

The resistor needs to be connected in a circuit with the power supply, with the ammeter and voltmeter used to take the necessary measurements. Either the given data needs to be extrapolated to the range of interest, or a point at 100°C is measured by immersing the resistor in the hot water bath so that interpolation can be used. In either case a best-fit line should be drawn. Measurements of voltage and current are then taken with the resistor immersed in the liquid of unknown temperature, and are used to calculate a value for resistance. The line on the graph is then used to determine the temperature corresponding to that value of resistance.

<table>
<thead>
<tr>
<th>5. (a) 3 points</th>
<th>Distribution of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>For including all four circuit elements in a circuit diagram (power supply, resistor, voltmeter, and ammeter)</td>
<td>1 point</td>
</tr>
<tr>
<td>For connecting the power supply, ammeter, and resistor in a complete series circuit</td>
<td>1 point</td>
</tr>
<tr>
<td>For connecting the voltmeter in parallel with the power supply or resistor</td>
<td>1 point</td>
</tr>
</tbody>
</table>

Clear labels must be included to receive credit.  
One earned point was deducted if the circuit that was drawn would not work.

The brief outline of the steps to be followed was scored along with part (b), since it is natural to combine these into one discussion.

<table>
<thead>
<tr>
<th>5. (b) 5 points</th>
<th>Distribution of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>For using the boiling water bath to obtain another data point and then interpolating the data</td>
<td>2 points</td>
</tr>
<tr>
<td>One of these points was awarded for simply extrapolating the data, since this is a less precise method.</td>
<td></td>
</tr>
<tr>
<td>For indicating that measurements of the voltage and the current must be taken when the resistor is immersed in the liquid of unknown temperature</td>
<td>1 point</td>
</tr>
<tr>
<td>For indicating that the resistance must be calculated from the measurements (if an equation is included it must be correct)</td>
<td>1 point</td>
</tr>
<tr>
<td>For using the graph to obtain a temperature corresponding to the calculated resistance</td>
<td>1 point</td>
</tr>
</tbody>
</table>
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Question 5 (cont.)

5. (c) 2 points

For any reasonable answer clearly stated as an assumption
One point was awarded for a less complete but still reasonable answer, or a true
statement that is not a relevant assumption.

Examples of full-credit answers:
Resistance versus temperature must be linear throughout the range of interest.
The temperature of the boiling water is 100°C (only awarded if hot water bath was
used in part (b) to allow interpolation).
Heat from the resistor does not significantly affect the temperature of the liquid
it is immersed in.
Resistance of the connecting wires is negligible, with an explanation of how this would
affect the measurements.

Examples of partial-credit answers:
Resistance is proportional to temperature.
Resistance of the connecting wires is negligible, with no explanation.
Reference to impact of voltmeter or ammeter on the measurement
No heat transferred to or from the environment
1988 Q3

3.

(a) 5 points

\[ R_{2,10} = \text{resistance of the 2 \( \Omega \) and 10 \( \Omega \) resistors in series} \]

\[ R_{2,10} = 2 \Omega + 10 \Omega = 12 \Omega \]

1 point

\[ R_{4,2,10} = \text{resistance of the combination of 2 \( \Omega \), 4 \( \Omega \), and 10 \( \Omega \) resistors} \]

\[ \frac{1}{R_{4,2,10}} = \frac{1}{4 \Omega} + \frac{1}{12 \Omega} = \frac{4}{12 \Omega} \]

\[ R_{4,2,10} = 3 \Omega \]

1 point

\[ R_{\text{total}} = 6 \Omega + 3 \Omega = 9 \Omega \]

1 point

\[ I_{\text{batt}} = \frac{E}{R} = \frac{72 \text{ V}}{9 \Omega} \] or \( V = IR \), with correct substitutions

1 point

\[ I = 8 \text{ A} \]

1 point

(b) 3 points

\[ V_{2,10} = 72 \text{ V} - (6 \Omega)(8 \text{ A}) = 24 \text{ V} \]

1 point

\[ I_{10} = I_{2,10} = \frac{24 \text{ V}}{12 \Omega} \]

1 point

\[ I_{10} = 2 \text{ A} \]

1 point

Alternate solution: (Alternate Points)

\[ I_4R_4 = I_{2,10}R_{2,10} \text{ (Potential differences equal)} \] (1 point)

\[ I_4 + I_{2,10} = 8 \text{ A} \text{ (Kirchoff's law)} \] (1 point)

These two equations may be solved for \( I_4 \) and \( I_{2,10} \)

\[ I_{10} = I_{2,10} = 2 \text{ A} \] (1 point)

(c) 1 point

\[ V_{10} = I_{10}R_{4} = (2 \text{ A})(10 \Omega) = 20 \text{ V} \]

1 point

(d) 3 points

\[ C = \text{Q}/V \]

1 point

\[ Q = CV = (3 \times 10^{-6} \text{ F})(20 \text{ V}) \]

1 point

\[ Q = 60 \mu C \]

1 point
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3. (continued)
(e) 2 points

Energy: \[ U = \frac{1}{2}CV^2 \]

\[ U = \frac{1}{2}(3 \times 10^{-6} \text{ F})(20 \text{ V})^2 = 6 \times 10^{-4} \text{ J} \]

Credit also given for correct solutions using equivalent expressions such as \[ U = \frac{1}{2} \frac{Q^2}{C} \]
or \[ U = \frac{1}{2}QU \]

Extra 1 point awarded for all units correct

Distribution of points

1 point

1 point

1 point
Question 2

15 points total

(a) 3 points

For the correct formula for total capacitance in series
\[ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{OR} \quad C_T = \frac{C_1 C_2}{C_1 + C_2} \]

For correct substitution
\[ \frac{1}{C_T} = \frac{1}{12 \mu F} + \frac{1}{6 \mu F} \quad \text{OR} \quad C_T = \frac{(12 \mu F)(6 \mu F)}{12 \mu F + 6 \mu F} \]

For the correct numerical answer
\[ C_T = 4 \mu F \]

(b) 3 points

The capacitors are fully charged so current flows through the resistors but not the capacitors.

For calculating the total resistance in series
\[ R_T = R_1 + R_2 = 10 \Omega + 20 \Omega = 30 \Omega \]

For use of correct form of Ohm's law
\[ I = \frac{V}{R} = \frac{6 \text{ V}}{30 \Omega} \]

For the correct answer
\[ I = 0.2 \text{ A} \]

(c) 3 points

Potential difference between \( A \) and \( B \) is the voltage across the 20 \( \Omega \) resistor

For a correct form of Ohm's law
\[ V = IR \]

For correct substitutions for \( I \) from part (b) and for \( R \)
\[ V = (0.2 \text{ A})(20 \Omega) \]

For the correct answer
\[ V = 4 \text{ V} \]

Note: 1 point was subtracted for indicating a wrong unit.

*Alternately*, full credit could be obtained for finding the voltage across the 10 \( \Omega \) resistor and subtracting it from 6 V or for recognizing that the voltages across the 20 \( \Omega \) and 10 \( \Omega \) resistors would add to 6 V and be in a 2/1 ratio, and using this to obtain the correct answer.
(d) 4 points

For using the correct formula to determine the charge
\[ Q = CV \]
1 point

For correct substitution of value of \( C \) from part (a)
1 point

For correct substitution of value of \( V \) from part (c)
1 point

\[ Q = (4 \times 10^{-6} \text{ F})(4 \text{ V}) \]

For the correct answer
1 point

\[ Q = 16 \times 10^{-6} \text{ C} = 16 \mu\text{C} \]

*Alternately,* full credit could be obtained by first determining the voltage across the 6 \( \mu \text{F} \) capacitor (which can be done one way by recognizing that the voltages across the two capacitors are in a 2/1 ratio and sum to 4 V) and substituting this value for \( V \) and the value for \( C \) of 6 \( \mu \text{F} \) into the equation \( Q = CV \).

(e) 2 points

For checking the box “remains the same”
1 point

For a reasonable justification
1 point

Example: No current is flowing from \( A \) to \( P \) to \( B \). Therefore breaking the circuit at point \( P \) does not affect the current in the outer loop, and therefore will not affect the potential difference between \( A \) and \( B \) (or across the 20 \( \Omega \) resistor).