

Physics Olympiad Competition 2012/2013

A2 Challenge Solutions

Mark Scheme Sept/Oct 2012

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Allow error carried forward where this gives sensible answers.

Answers should be to an appropriate number of significant figures. This should normally be the same number of significant figures given for the data in the question.

Question 1

Let the mass of each liquid be m

Density = mass / volume 1

Mass of mixture = $2m$

Volume of mixture $= \frac{m}{800} + \frac{m}{1200}$ 2

$$= \frac{m}{480}$$

\Rightarrow Density of mixture = $2m \div \frac{m}{480}$

$= 960 \text{ kg m}^{-3}$ unit needed in final answer 2

TOTAL 5

Question 2

a. $1 \text{ kW hr} = 1,000 \times 3,600 \text{ J} = 3.6 \times 10^6 \text{ J}$ 2

b. Reactor electrical energy $= 15 \times 10^9 \text{ kW hr in one year}$

$= 15 \times 10^9 \times 3.6 \times 10^6 \text{ J in one year}$
 $= 5.4 \times 10^{16} \text{ J in one year}$ 1

Energy converted in the reactor = $5.4 \times 10^{16} / 0.35$

$= 1.54 \times 10^{17} \text{ J}$ 1

Rate of energy loss in one second $= \frac{1.54 \times 10^{17}}{365 \times 24 \times 3600}$
 $= 4.9 \times 10^9 \text{ J s}^{-1}$ 2

Mass loss per second = energy loss per second $\div c^2$ 1

$$= \frac{4.9 \times 10^9}{9 \times 10^{16}} \text{ kg s}^{-1}$$

$$= 5.4 \times 10^{-8} \text{ kg s}^{-1}$$

$$= 54 \text{ mg s}^{-1}$$

1

TOTAL 8

Question 3

- a. The speed of sound in sea water, v_{water} can be found by knowing the speed of sound in air, which is given as $v_{\text{air}} = 330 \text{ m s}^{-1}$.

$$\text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

1

$$\text{Distance of charge behind vessel} = v_{\text{air}} \times 3.05$$

$$\Rightarrow v_{\text{water}} = v_{\text{air}} \times \frac{3.05}{0.650}$$

2

$$= 1550 \text{ m s}^{-1}$$

1

- b. Length of route (i) is $2a = v_{\text{water}} \times 0.65$

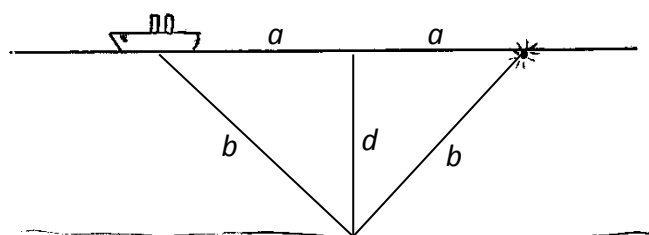
$$= 1007 \text{ m}$$

2

$$\text{Length of route (iii) is } 2b = v_{\text{water}} \times 3.26$$

$$= 5048 \text{ m}$$

2



The depth of the ocean, d , may easily be found by Pythagoras: $d = \sqrt{b^2 - a^2}$

1

$$= 2470 \text{ m}$$

2

TOTAL 11

Question 4

- a. The maximum expected discrepancy will occur when one of the resistors is 5% above its nominal value and the other is 5% below. 1

For example,

if $R_1 = 10.5 \text{ k}\Omega$ and $R_2 = 9.5 \text{ k}\Omega$, the output voltage will be $V_{out} = \frac{R_1}{R_1 + R_2} \times 12\text{V}$ 2

$$= \frac{10.5}{20} \times 12\text{V}$$

$$= 6.30 \text{ V}$$

[if $R_1 = 9.5 \text{ k}\Omega$ and $R_2 = 10.5 \text{ k}\Omega$, the output voltage will be $V_{out} = 5.70 \text{ V}$]

\Rightarrow the maximum discrepancy to be expected is 0.30 V 1

- b. If $V_{out} = 6.10 \text{ V}$ then $\frac{R_1}{R_1 + R_2} = 0.5083$

$\Rightarrow R_2 = 9.67 \text{ k}\Omega$, since R_1 is known to be $10 \text{ k}\Omega$ 2

To produce an output voltage of 6.00 V , the resistance of the lower part of the divider must also be $9.67 \text{ k}\Omega$, which can be achieved by adding a resistance R in parallel with R_1 . 1

$$\Rightarrow \frac{1}{9.67} = \frac{1}{10} + \frac{1}{R} \quad 1$$

$$\Rightarrow \frac{1}{R} = 0.00339 \text{ k}\Omega^{-1}$$

$$\Rightarrow R = 295 \text{ k}\Omega \quad (= 300 \text{ k}\Omega) \quad 2$$

TOTAL 10

Question 5

$$f \propto \frac{\sqrt{T}}{d} \quad 2$$

$$\Rightarrow f_G = \frac{\sqrt{T_G/T_B}}{d_G/d_B} \times f_B \quad 2$$

$$= \frac{\sqrt{1.56}}{1.56} \times f_B \quad 2$$

$$= \frac{1}{\sqrt{1.56}} \times f_B$$

$$f_B = 245 \text{ Hz} \Rightarrow f_G = 196 \text{ Hz} \quad 2$$

TOTAL 8

Question 6

$R = kE^4$ and when E becomes slightly greater by an amount e , then R will become slightly greater by an amount r 2

So we may write $R + r = k(E + e)^4$ 1

And this can be expanded when $e \ll E$ by writing it as

$$R + r = kE^4(1 + e/E)^4 \quad \text{and if } (1 + x)^n \approx 1 + nx \quad 1$$

Then $R + r \approx kE^4(1 + 4e/E)$
Which becomes $R + r \approx kE^4 + 4kE^3e$

So that $r \approx 4kE^3e$ and using $R = kE^4$ 1

$$\frac{r}{R} = 4 \frac{e}{E} \quad 1$$

So if $\frac{e}{E}$ is 1% then $\frac{r}{R}$ is 4% 2

TOTAL 8