Indian National Physics Olympiad - 2011
Solutions

Please note that alternate/equivalent solutions may exist. Brief solutions are given below.

1. (a) $F_x = \dfrac{-\mu_0 e v_y I}{2\pi x}$

   $F_y = \dfrac{\mu_0 e v_x I}{2\pi x}$

   (b) $v_x = \sqrt{v_0^2 - \left(\dfrac{e\mu_0 I}{2\pi m}\log\dfrac{x}{a}\right)^2}$

   (c) $x_{max} = a\exp\left(2\pi v_0 m/e\mu_0 I\right)$

2. (a) $\Delta x = \dfrac{\mu_l y d}{D} - (\mu_g - \mu_l)t_g$

   Also acceptable: $\Delta x = (\mu_g - \mu_l)t_g - \dfrac{\mu_l y d}{D}$ **or** $\dfrac{yd}{D} - \left(\dfrac{\mu_g}{\mu_l} - 1\right)t_g$

   (b) $y = \dfrac{t-4}{10-t} \times 1.8 \times 10^{-2}$ m for $t \leq 5$ s

   $= 3.6 \times 10^{-3}$ m for $t > 5$ s

   (c) $t_m = 4$ s

   (d) $v = 3.0 \times 10^{-3}$ m·s^{-1}

   (e) $\Delta t = 6.7 \times 10^{-2}$ s

3. (a)

$P_1 = \dfrac{R\alpha T_0}{V_0}$	$P_2 = \dfrac{RT_0\alpha^{\gamma/\gamma-1}}{nV_0}$	$P_3 = \dfrac{RT_0}{nV_0}$	$P_4 = \dfrac{RT_0}{V_0\alpha^{1/\gamma-1}}$
$V_1 = V_0$	$V_2 = \dfrac{nV_0}{\alpha^{1/\gamma-1}}$	$V_3 = nV_0$	$V_4 = \alpha^{1/\gamma-1}V_0$
$T_1 = \alpha T_0$	$T_2 = \alpha T_0$	$T_3 = T_0$	$T_4 = T_0$

   (b) $W_{12} = R\alpha T_0 \log\left(\dfrac{n}{\alpha^{1/\gamma-1}}\right)$

   $W_{23} = -\dfrac{RT_0(1-\alpha)}{\gamma-1}$

   $W_{34} = RT_0\log\left(\dfrac{\alpha^{1/\gamma-1}}{n}\right)$

   $W_{41} = -\dfrac{RT_0(\alpha-1)}{\gamma-1}$

   (c) $Q = R\alpha T_0\log\left(\dfrac{n}{\alpha^{1/\gamma-1}}\right)$

   Also acceptable: $Q = RT_0(\alpha-1)\log\left(\dfrac{n}{\alpha^{1/\gamma-1}}\right)$

4. (a) Taking $q_1 = q_2 = e$, $r_n = n^2 a_0 - \beta$

   (b) $E_n = -\dfrac{q_1 q_2}{8\pi\epsilon_0(n^2 a_0 - \beta)}$

   (c) ΔE =11.5 eV ($\pm$0.15 eV acceptable)

5. (a) $m\frac{d\vec{v}}{dt} = -e\left(\vec{E} + \vec{v} \times \vec{B}\right) - \frac{m\vec{v}}{\tau}$

(b) $\omega_c = eB/m = 10^{12}$ rad$\cdot$ s^{-1}

(c) $\sigma_0 = ne^2\tau/m = 5.8 \times 10^7$ (ohm$\cdot$ m)$^{-1}$

(d)

$$\sigma_{xy} = -\frac{\sigma_0 \tau \omega_c}{1+\omega_c^2\tau^2}; \qquad \sigma_{xz} = 0$$
$$\sigma_{yy} = \frac{\sigma_0}{1+\omega_c^2\tau^2}; \qquad \sigma_{yz} = 0$$
$$\sigma_{zy} = 0; \qquad \sigma_{xz} = \sigma_0$$

(e) See Fig. (1). Either of Fig. (1a) or (1b) or (1c) is acceptable.

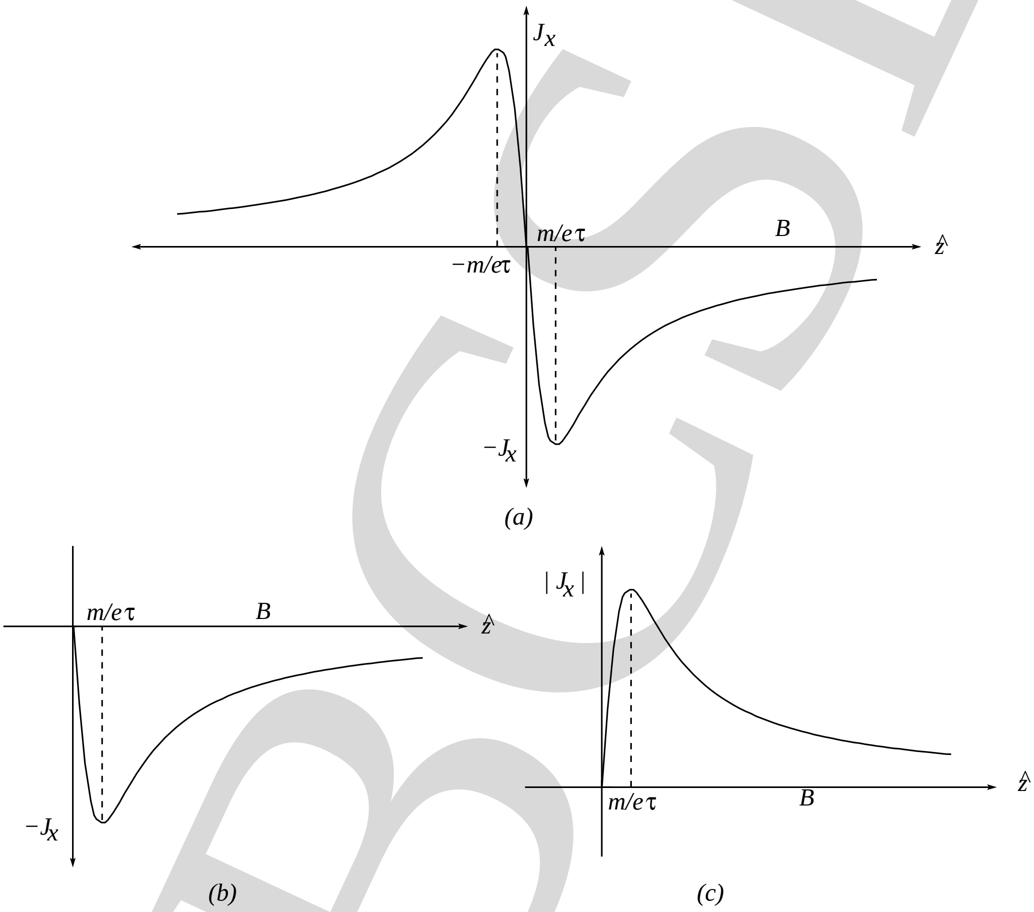

Figure 1: j_x vs B

(f) $B = 229$ T

6. (a) $V_A = \frac{1-\gamma}{1+\gamma}V_0$

$V_B = \frac{2V_0}{1+\gamma}$

$V_C = 0$

(b) See Fig. (2) for free body diagrams.
Equations of motion:
$m\frac{d^2x_B}{dt^2} = -F_B$ and $m\frac{d^2x_C}{dt^2} = F_C$

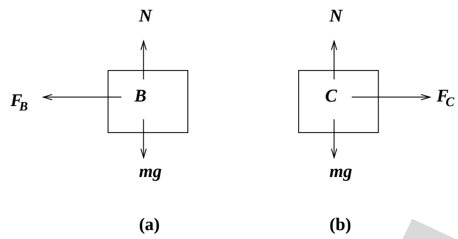

Figure 2: (a) Free body diagram for the block B. Here $F_B = k\,(L - (x_C - x_B))$ (b) Free body diagram for the block C. Here $F_C = k\,(L - (x_C - x_B))$.

(c) $\omega = \sqrt{\dfrac{2k}{m}}$

$\alpha = \dfrac{V_0}{1+\gamma}$

$\beta = \dfrac{V_0}{\omega(1+\gamma)}$

(d) $0 < \gamma < 2/3\pi$

7. (a) We can define $D = m^2\omega^4 - 4\alpha\delta$ and $D' = m^2\omega^4 - \dfrac{16}{3}\alpha\delta$. There are four possibilities. See Fig. (3) for detailed graphs.

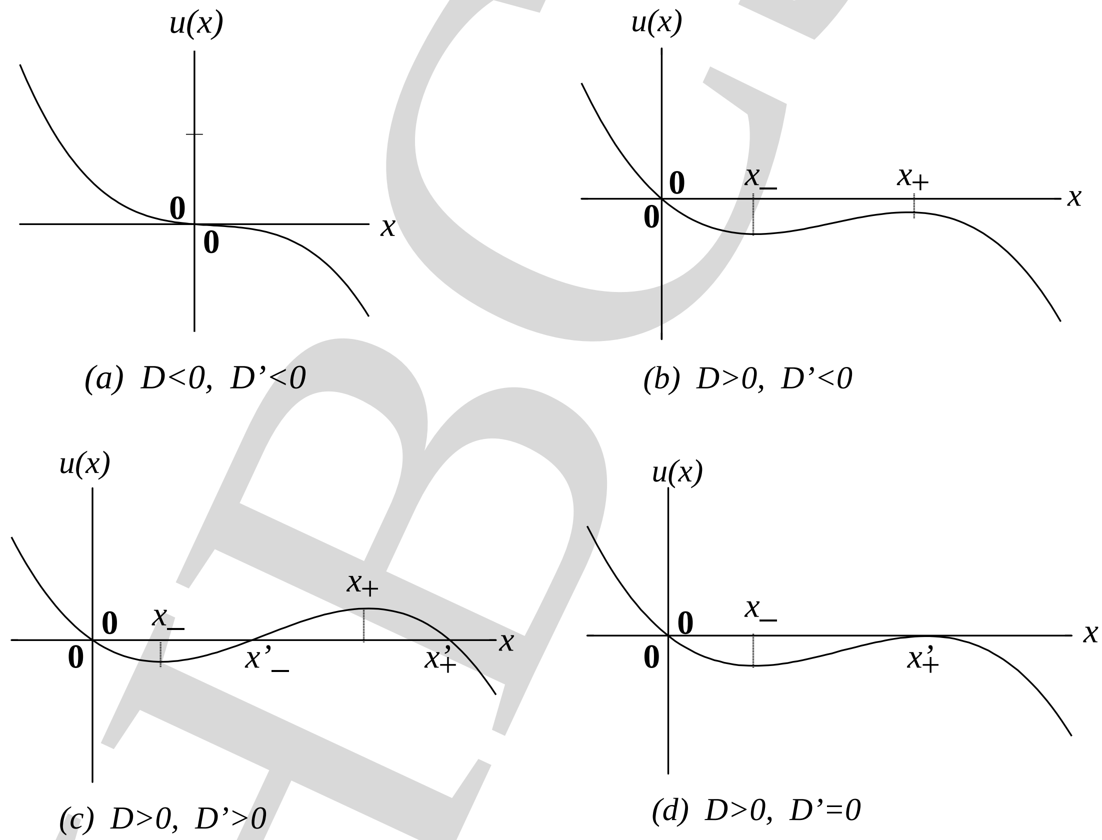

Figure 3: Here $x_\pm = (m\omega^2 \pm \sqrt{D})/2\alpha$ and $x'_\pm = 3(m\omega^2 \pm \sqrt{D'})/4\alpha$.

(b) See Fig. (4).

For $0 < x < 0.6$ motion is bounded on the left and periodic.

$x \in [2.4, \infty[$ motion is partially bounded and not periodic.

$x < 0$ and $0.6 < x < 2.4$ forbidden motion.

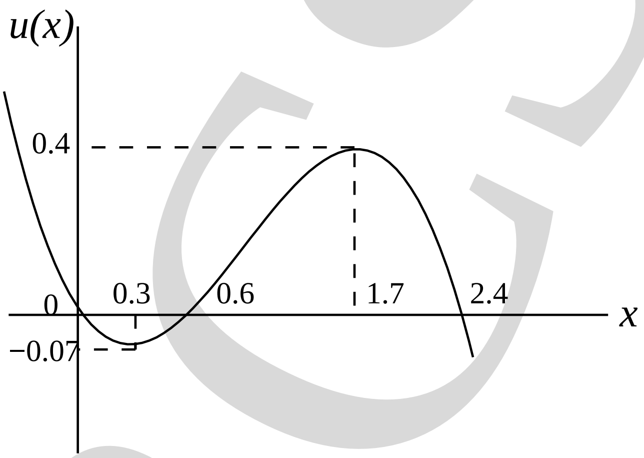

Figure 4:

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