Theoretical Competition
25 April 2010

Student Code ☐☐☐–☐

Question Number 1

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ANSWER SHEET

Theoretical Question 1
Particles and Waves

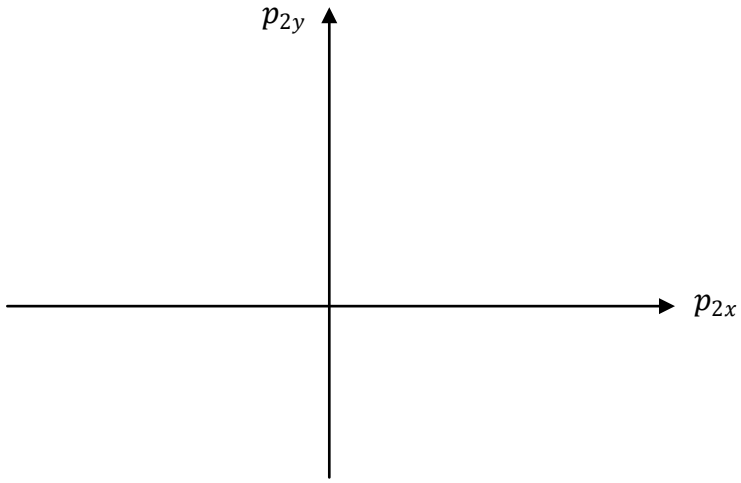
Do not write in any box marked with a solidus (oblique stroke, /).

Part A. Inelastic scattering and compositeness of particles

(a)(i) Q in terms of m, M, p_1, p_{2x}, and p_{2y}

Expression of $Q =$							
0.2 pt	/	/	/	/	/	/	/

(ii) Plot of a condition relating p_1, p_{2x}, and p_{2y} for an elementary target as a curve with p_{2x}-intercepts specified. Label regions with $Q < 0$, $Q = 0$, $Q > 0$.



0.7 pt	/	/	/	/	/	/	/

Region(s) of Q allowed by a stationary composite target in its ground state before scattering.

Allowed Q region(s):							
0.2 pt	/	/	/	/	/	/	/

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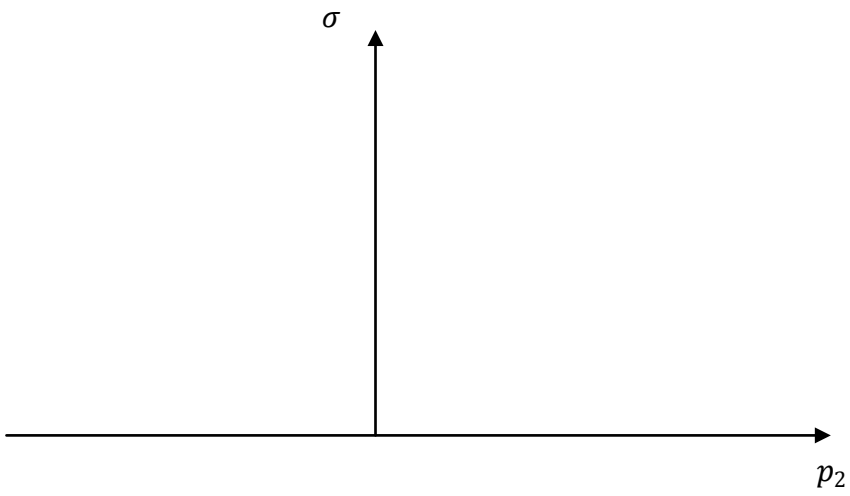
(b)(i) The equation relating x to $Q, \theta, d_0, m, k, M, p_1$ and p_2.

0.7 pt	/	/	/	/	/	/	/

(ii) Threshold value p_c of p_2.

$p_c =$							
1.1 pt	/	/	/	/	/	/	/

Plot of σ versus p_2 for given p_1 and $M = 3m$ with range of σ and p_2 specified.



1.1 pt	/	/	/	/	/	/	/

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Part B. Waves on a string

(c) Period of vibration T for the string.

$T =$							
0.5 pt	/	/	/	/	/	/	/

Shape of the string at $t = T/8$ (specify important lengths and angles).

1.7 pt	/	/	/	/	/	/	/

(d) The total mechanical energy of the vibrating string.

0.8 pt	/	/	/	/	/	/	/

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Part C. The expanding universe

(e) Distance (in units of Mpc) of the star from us.

$L(t_e) =$							
2.2 pt	/	/	/	/	/	/	/

(f) The receding velocity (in units of c) of the star.

$v(t_0) =$							
0.8 pt	/	/	/	/	/	/	/

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Theoretical Question 2

Strong Resistive Electromagnets

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Part A. Magnetic fields on the axis of the coil

(a) x-component $B(x)$ of the magnetic field on the axis (in terms of a, D, I, ℓ, μ_0).

Expression of $B(x) =$							
1.0 pt	/	/	/	/	/	/	/

(b) The current I_0 when $B(0) = 10.0$ T (expressed in terms of a, D, $B(0)$, ℓ, μ_0).

Expression of $I_0 =$ Value of $I_0 =$							
0.4 pt	/	/	/	/	/	/	/

Part B. The upper limit of current

(c) The outward normal force per unit length $\Delta F_n/\Delta s$ (in terms of a, D', I, μ_0).

Expression of $\frac{\Delta F_n}{\Delta s} =$							
1.2 pt	/	/	/	/	/	/	/

The tension F_t along the wire (in terms of a, D', I, μ_0).

Expression of $F_t =$							
0.6 pt	/	/	/	/	/	/	/

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(d) The current I_b at which the turn will break (expressed in terms of a, b, D, σ_b, μ_0).

Expression of I_b = Value of I_b =							
0.8 pt	/	/	/	/	/	/	/

The magnetic field B_b at O when the current is I_b (expressed in terms of a, I_b, μ_0).

Expression of B_b = Value of B_b =							
0.4 pt	/	/	/	/	/	/	/

Part C. Rate of temperature rise

(e) The power density of heat generation in the coil.

Expression: Value:							
0.5 pt	/	/	/	/	/	/	/

(f) The time rate of change $\dot{T}$ of temperature in the coil.

Expression of $\dot{T}$ = Value of $\dot{T}$ =							
0.5 pt	/	/	/	/	/	/	/

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Part D. A pulsed-field magnet

(g) Expressions for the inductance L and resistance R.

Expression of L = Expression of R =							
0.6 pt	/	/	/	/	/	/	/

Values of inductance L and resistance R.

Value of L = Value of R =							
0.4 pt	/	/	/	/	/	/	/

(h) Expressions for α and ω (in terms of R, L, and C).

Expression of α = Expression of ω =							
0.8 pt	/	/	/	/	/	/	/

Values of α and ω.

Value of α = Value of ω =							
0.4 pt	/	/	/	/	/	/	/

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(i) Expression of I_m (in terms of α, ω, θ_0, V_0 and C).

Expression of I_m =							
0.6 pt	/	/	/	/	/	/	/

Maximum initial voltage V_{0b} for which I_m will not exceed I_b of Problem (d).

Value of V_{0b} =							
0.4 pt	/	/	/	/	/	/	/

(j) The total amount of heat ΔE dissipated in the coil (in terms of α, ω, θ_0, V_{0b} and C).

Expression of ΔE = Value of ΔE =							
1.0 pt	/	/	/	/	/	/	/

The temperature increase ΔT of the coil.

Expression of ΔT = Value of ΔT =							
0.4 pt	/	/	/	/	/	/	/

ANSWER SHEET

Theoretical Question 3

Electron and Gas Bubbles in Liquids

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Part A. An electron bubble in liquid helium

(a) Relation between P_{He}, P_{e}, and σ.

Expression of $P_{\mathrm{e}} =$							
0.4 pt	/	/	/	/	/	/	/

Relation between E_{k} and P_{e}.

Expression:							
1.0 pt	/	/	/	/	/	/	/

(b) The smallest possible kinetic energy E_0 as a function of R.

Expression of $E_0 =$							
0.8 pt	/	/	/	/	/	/	/

(c) The bubble's equilibrium radius R_{e} when $E_{\mathrm{k}} = E_0$ and $P_{\mathrm{He}} = 0$.

Expression of $R_{\mathrm{e}} =$ Value of $R_{\mathrm{e}} =$							
0.6 pt	/	/	/	/	/	/	/

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(d) Condition satisfied by R and P_{He} for locally stable equilibrium at radius R.

Expression:							
0.6 pt	/	/	/	/	/	/	/

(e) The threshold pressure P_{th} below which no equilibrium is possible for the bubble.

Expression of $P_{\mathrm{th}} =$							
0.6 pt	/	/	/	/	/	/	/

Part B. Single gas bubble in liquid — collapsing and radiation

(f) Work dW done on the liquid when the bubble's radius changes from R to $R + dR$.

Expression of $dW =$							
0.4 pt	/	/	/	/	/	/	/

Values of the exponents m and n.

m = n =							
0.4 pt	/	/	/	/	/	/	/

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(g) Pressure $P \equiv P(R)$ and temperature $T \equiv T(R)$ as a function of R.

Expression of $P \equiv P(R) =$ Expression of $T \equiv T(R) =$							
0.6 pt	/	/	/	/	/	/	/

(h) The coefficient μ in terms of R_i and P_0.

Expression of $\mu =$							
0.6 pt	/	/	/	/	/	/	/

(i) Values of the constant C_m.

Value of $C_m =$							
0.4 pt	/	/	/	/	/	/	/

The minimum radius R_m for $R_i = 7R_0$.

Value of $R_m =$							
0.3 pt	/	/	/	/	/	/	/

The temperature T_m of the gas at β_m.

Value of $T_m =$							
0.3 pt	/	/	/	/	/	/	/

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(j) The radius β_u at which the radial speed $u \equiv |\dot{\beta}|$ reaches its maximum value.

Expression of $\beta_u =$ Value of $\beta_u =$							
0.6 pt	/	/	/	/	/	/	/

The value of $\bar{u}$ of the dimensionless radial speed u at $\beta = \bar{\beta} \equiv \frac{1}{2}(\beta_{\mathrm{m}} + \beta_u)$.

Value of $\bar{u} =$							
0.4 pt	/	/	/	/	/	/	/

The time duration Δt_{m} for β to diminish from β_u to the minimum value β_{m}.

Expression of $\Delta t_{\mathrm{m}} =$ Value of $\Delta t_{\mathrm{m}} =$							
0.6 pt	/	/	/	/	/	/	/

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(k) The power $\dot{E}$ supplied to the bubble at β.

Expression of $\dot{E} =$							
0.6 pt	/	/	/	/	/	/	/

The upper bound of the emissivity a.

Expression of $a =$ Value of $a =$							
0.8 pt	/	/	/	/	/	/	/