

FY10A0100 – Essential Physics

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Calculator may be used in the exam.

Please write down the units in the calculations.

Answer only to five questions.

If all of the questions are answered, the best answer will be discarded :(

Good luck and have fun :)

1. It's rocket science**8 points**

A physics student builds a rocket for himself. He launches the rocket straight up, against the gravity of the Earth. The mass of the rocket together with the student is 100 kg and the rocket generates 1000 N of constant thrust.

- (a) 4 p: The rocket breaks down at $t = 2$ s. What is the rocket's velocity and height from the ground at this moment? Air resistance is not taken into account.
- (b) 4 p: After breaking down, the rocket will not generate any thrust and it will eventually hit the ground. What will be the velocity of the rocket at the crash? *Hint: there are many ways to solve this, think what would be the easiest one for you.*

2. Without risks this time**8 points**

The physics student ($m = 70$ kg) goes skiing again. This time he chooses an easy small hill, with slope of $\theta = 30^\circ$. The kinetic friction coefficient is $\mu_k = 0.05$. Air resistance is not taken into account. What is his acceleration? Draw a detailed force diagram with all the forces involved.

3. Bowling**8 points**

A physics student goes bowling. He releases the bowling ball ($M = 5$ kg) with speed of $V_0 = 8 \frac{\text{m}}{\text{s}}$. The ball travels exactly to the x -direction (the angle of its trajectory with respect to the x -axis is $\Theta_0 = 0^\circ$). The bowling ball hits three bowling pins, each of them has mass of $m = 1.5$ kg. After that, the pins will have the following velocities:

- Pin a : this pin will have the speed of $v_a = 6 \frac{\text{m}}{\text{s}}$ and it will travel to the direction of the x -axis ($\theta_a = 0^\circ$).
- Pin b : this pin will have the speed of $v_b = 8 \frac{\text{m}}{\text{s}}$ and the angle of its trajectory with respect to the x -axis will be $\theta_b = 30^\circ$.
- Pin c : this pin will have velocity of $\mathbf{v}_c = 5 \frac{\text{m}}{\text{s}} \hat{\mathbf{i}} + 3 \frac{\text{m}}{\text{s}} \hat{\mathbf{j}}$.

What will be the speed V_1 (magnitude of velocity) and angle of its trajectory with respect to the x -axis (Θ_1) of the bowling ball after the collisions?

4. This is an easy question, you can do it**8 points**

A physics student has 0.5 kg of ice in a small steel kettle (mass 0.4 kg) in the freezer. Both the ice and the kettle are in the freezer temperature, which is -20°C . He puts the kettle on the stove until all the ice first melts and then boils away (there is no water left at the end) and the kettle has reached an average temperature of 200°C (I don't know why, I guess he is not very good at cooking). How much energy does the whole process take?

For water, the density is $1000 \frac{\text{kg}}{\text{m}^3}$, the latent heat of fusion is $334 \frac{\text{kJ}}{\text{kg}}$ and the latent heat of vaporization is $2256 \frac{\text{kJ}}{\text{kg}}$. The specific heat for liquid water is $4186 \frac{\text{J}}{\text{kg}\cdot\text{K}}$, for solid water (ice) it is $2090 \frac{\text{J}}{\text{kg}\cdot\text{K}}$ and for steel it is $452 \frac{\text{J}}{\text{kg}\cdot\text{K}}$.

5. Gas on a journey**8 points**

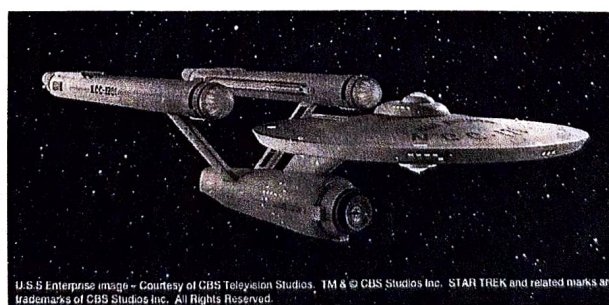
A physics student has 100 moles of ideal monoatomic gas at pressure of 100 kPa and temperature of 20°C . He then takes the gas to a trip in the pV -diagram. The initial situation corresponds to point 1. In the first step he heats the gas isochorically (in constant volume) to 100°C . This state corresponds to point 2. In the second step he increases the volume of this gas to 3 m^3 isobarically (in constant pressure). This state corresponds to point 3.

- (a) 2 p: Draw this path in the pV -diagram.
- (b) 3 p: What is the temperature at the point 3?
- (c) 3 p: How much work the gas performed during this process?

6. Starship Enterprise**8 points**

A physics student grows up and builds the antimatter drive of the Starship Enterprise spaceship familiar from Star Trek. It uses an antimatter propulsion system where antiprotons (that are like protons but with negative charge of $-e$) annihilate with normal matter, producing pure energy in the form of gamma rays (high-energy photons). The antiproton fuel is stored with a magnetic trap in a vacuum chamber (since the fuel can not touch normal matter).

The magnetic trap has a strong uniform magnetic field which causes the antiprotons, that are moving at $4 \cdot 10^6 \frac{\text{m}}{\text{s}}$, to revolve indefinitely in a circular path with radius of 2 m. How strong is the magnetic field? *Hint: you will have to combine different equations.*



Equations and constants

$$\begin{aligned}
\sin 30^\circ &= \frac{1}{2}, & \cos 30^\circ &= \frac{\sqrt{3}}{2} \approx 0.866\,025, & g &= 9.8 \frac{\text{m}}{\text{s}^2}, \\
0^\circ\text{C} &= 273.15\,\text{K}, & N_A &= 6.02 \cdot 10^{23} \frac{1}{\text{mol}}, & k_B &= 1.38 \cdot 10^{-23} \frac{\text{J}}{\text{K}}, \\
R &= 8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}}, & m_e &= 9.11 \cdot 10^{-31} \text{kg}, & m_p &= 1.67 \cdot 10^{-27} \text{kg}, \\
e &= 1.60 \cdot 10^{-19} \text{C}, & k_e &= 8.988 \cdot 10^9 \frac{\text{Nm}^2}{\text{C}^2}, & \mu_0 &= 4\pi \cdot 10^{-7} \frac{\text{Tm}}{\text{A}}, \\
1\,\text{A} &= 1 \frac{\text{C}}{\text{s}}, & 1\,\text{Wb} &= 1\,\text{V} \cdot \text{s}, & 1\,\text{T} &= 1 \frac{\text{V} \cdot \text{s}}{\text{m}^2} = 1 \frac{\text{kg}}{\text{A} \cdot \text{s}^2}, \\
\mathbf{A} \cdot \mathbf{B} &= \sum_n A_n B_n, & \mathbf{A} \cdot \mathbf{B} &= AB \cos \theta, & \mathbf{A} \cdot \mathbf{A} &= A^2, \\
(2\text{D}): \quad \mathbf{A} &= A_x \hat{\mathbf{i}} + A_y \hat{\mathbf{j}}, & \mathbf{A} \cdot \mathbf{B} &= A_x B_x + A_y B_y, & A &= \sqrt{A_x^2 + A_y^2}, \\
(3\text{D}): \quad \mathbf{A} &= A_x \hat{\mathbf{i}} + A_y \hat{\mathbf{j}} + A_z \hat{\mathbf{k}}, & \mathbf{A} \cdot \mathbf{B} &= A_x B_x + A_y B_y + A_z B_z, & A &= \sqrt{A_x^2 + A_y^2 + A_z^2}, \\
(2\text{D}): \quad A_x &= A \cos \theta_A, & A_y &= A \sin \theta_A, & \tan \theta_A &= \frac{A_y}{A_x}, \\
(3\text{D}): \quad \mathbf{A} \times \mathbf{B} &= (A_y B_z - A_z B_y) \hat{\mathbf{i}} + (A_z B_x - A_x B_z) \hat{\mathbf{j}} + (A_x B_y - A_y B_x) \hat{\mathbf{k}}, & \|\mathbf{A} \times \mathbf{B}\| &= AB \sin \theta, \\
\mathbf{r} &= x \hat{\mathbf{i}} + y \hat{\mathbf{j}} + z \hat{\mathbf{k}}, & \mathbf{v} &= v_x \hat{\mathbf{i}} + v_y \hat{\mathbf{j}} + v_z \hat{\mathbf{k}}, & \mathbf{a} &= a_x \hat{\mathbf{i}} + a_y \hat{\mathbf{j}} + a_z \hat{\mathbf{k}}, \\
\mathbf{v}_{\text{avg}} &= \frac{\Delta \mathbf{r}}{\Delta t} = \frac{\mathbf{r}_1 - \mathbf{r}_0}{t_1 - t_0}, & \mathbf{v}(t) &= \frac{d\mathbf{r}(t)}{dt}, & \omega_{\text{avg}} &= \frac{\Delta \theta}{\Delta t} = \frac{\theta_1 - \theta_0}{t_1 - t_0}, & \omega(t) &= \frac{d\theta(t)}{dt}, \\
\mathbf{a}_{\text{avg}} &= \frac{\Delta \mathbf{v}}{\Delta t} = \frac{\mathbf{v}_1 - \mathbf{v}_0}{t_1 - t_0}, & \mathbf{a}(t) &= \frac{d\mathbf{v}(t)}{dt}, & \alpha_{\text{avg}} &= \frac{\Delta \omega}{\Delta t} = \frac{\omega_1 - \omega_0}{t_1 - t_0}, & \alpha(t) &= \frac{d\omega(t)}{dt}, \\
\mathbf{r}(t) &= \mathbf{r}_0 + \mathbf{v}_0 t + \frac{1}{2} \mathbf{a} t^2, & \mathbf{v}(t) &= \mathbf{v}_0 + \mathbf{a} t, & \theta(t) &= \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2, & \omega(t) &= \omega_0 + \alpha t, \\
v^2 &= v_0^2 + 2a(x - x_0), & \omega^2 &= \omega_0^2 + 2\alpha(\theta - \theta_0), \\
\mathbf{a} &= \mathbf{a}_c + \mathbf{a}_t, & a_t &= R\alpha, & a_c &= \frac{v^2}{R}, & \mathbf{r}(t) &= R \cos(\omega t) \hat{\mathbf{i}} + R \sin(\omega t) \hat{\mathbf{j}}, \\
\mathbf{F}_{\text{tot}} &= \sum_n \mathbf{F}_n = \mathbf{F}_1 + \mathbf{F}_2 + \dots = m\mathbf{a}, & \tau_{\text{tot}} &= \sum_n \tau_n = \tau_1 + \tau_2 + \dots = I\alpha, \\
\mathbf{W} &= m, & f_s &\leq \mu_s N, & f_k &= \mu_k N, & \boldsymbol{\tau} &= \mathbf{r} \times \mathbf{F}, \\
\mathbf{p} &= m\mathbf{v}, & \mathbf{p}_{\text{tot}} &= \sum_n \mathbf{p}_n = \mathbf{p}_1 + \mathbf{p}_2 + \dots = \text{constant}, & \mathbf{p}_0^{\text{tot}} &= \mathbf{p}_1^{\text{tot}}, \\
U &= mg\Delta y, & K &= \frac{1}{2}mv^2, & K &= \frac{1}{2}I\omega^2, & K_0 + U_0 + W &= K_1 + U_1, \\
W_{AB} &= \int_{\text{path } AB} \mathbf{F} \cdot d\mathbf{r}, & W &= \mathbf{F} \cdot \Delta \mathbf{r}, & P(t) &= \frac{dW}{dt}, & P &= \mathbf{F} \cdot \mathbf{v}.
\end{aligned}$$

$$\begin{array}{llll}
\Delta L = \alpha L \Delta T, & \Delta A = 2\alpha A \Delta T, & \Delta V = \beta V \Delta T, & \\
Q = mc\Delta T, & Q = mL_f, & Q = mL_v, & m = nM, \\
pV = Nk_B T, & pV = nRT, & W = \int_{V_1}^{V_2} p dV, & W = p(V_2 - V_1), \\
W = nRT \ln \frac{V_2}{V_1}, & W = \frac{p_2 V_2 - p_1 V_1}{1 - \gamma}, & \gamma = \frac{C_p}{C_v}, & pV^\gamma = \text{constant}, \\
W = Q_h - Q_c, & e = \frac{W}{Q_h}, & K_R = \frac{Q_c}{W}, & K_P = \frac{Q_h}{W}, \\
e = 1 - \frac{T_c}{T_h}, & K_R = \frac{T_c}{T_h - T_c}, & K_P = \frac{T_h}{T_h - T_c}, & \\
\mathbf{F}_{12} = k \frac{q_1 q_2}{r_{12}^2} \hat{\mathbf{r}}_{12}, & \mathbf{F}_{\text{tot}} = kQ \sum_i \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i, & \mathbf{E}(\mathbf{P}) = k \sum_i \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i, & \mathbf{F} = q\mathbf{E}, \\
U = \frac{qQ}{r}, & V = \frac{U}{q}, & V = IR, & P = IV, \\
R_{\text{tot}} = \sum_i^N R_i, & R_{\text{tot}} = \left(\sum_i^N \frac{1}{R_i} \right)^{-1}, & \sum I_{\text{in}} = \sum I_{\text{out}}, & \sum V = 0, \\
\mathbf{F} = q\mathbf{v} \times \mathbf{B}, & F = qvB \sin \theta, & \mathbf{F} = \mathbf{l} \times \mathbf{B}, & F = IlB \sin \theta, \\
R = \frac{mv}{qB}, & \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_{\text{wire}} \frac{\mathbf{l} \times \hat{\mathbf{r}}}{r^2}, & B = \frac{\mu_0 I}{2\pi R}, & \\
\Phi = \int_S \mathbf{B} \cdot d\mathbf{A}, & \Phi = BA \cos \phi, & \epsilon = -N \frac{d\Phi}{dt}, & x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
\end{array}$$