

Physics Qualifying Examination

August 25, 2005 9 AM - 12:30 PM

This examination has general questions from six areas of physics:

1. Mechanics
2. Thermodynamics
3. Electricity and Magnetism
4. Optics & Waves
5. Mathematical Physics
6. Modern Physics

Attempt all problems using a separate sheet of paper for each.

Grading of the examination will be based on your approach to solving the problem, and on your application of basic physical principles. All problems are weighed equally.

FUNDAMENTAL PHYSICAL CONSTANTS

Planck constant $h = 6.626076 \times 10^{-34} J \cdot s$

Boltzmann constant $k_B = 1.38066 \times 10^{-23} J/K$

Elementary charge $e = 1.60217733 \times 10^{-19} C$

Avogadro number $N_A = 6.0221367 \times 10^{23} particles/mol$

Speed of light $c = 2.99792458 \times 10^8 m/s$

Permeability of vacuum $\mu_0 = 4\pi \times 10^{-7} T^2 \cdot m^3/J$

Permittivity of vacuum $\epsilon_0 = 8.854187817 \times 10^{-12} C^2/J \cdot m$

Fine structure constant $\alpha = 1/137.0359895$

Electron rest mass $m_e = 9.1093897 \times 10^{-31} kg$

Proton rest mass $m_p = 1.6726231 \times 10^{-27} kg$

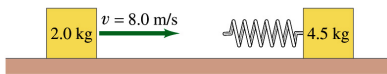
Gas constant $R = 8.31451 m^2 kg/s^2 \cdot K \cdot mol$

Gravitational constant $G = 6.673 \times 10^{-11} m^3/kg \cdot s^2$

Acceleration due to gravity $g = 9.80665 m/s^2$

I. Mechanics

1) A 2.0-kg block slides along a frictionless tabletop at 8.0 m/s toward a second block (at rest) of mass 4.5 kg. A coil spring, which obeys Hooke's law and has spring constant $k = 850 \text{ N/m}$, is attached to the second block in such a way that it will be compressed when struck by the moving block (see Fig.). What will be the maximum compression of the spring? (h) What will be the final velocities of the blocks after the collision? (c) Is the collision elastic?

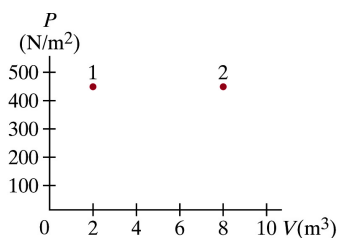


2) A refrigerator is approximately a uniform rectangular solid 2.5 m tall, 1.0 m wide, and 1.5 m deep. If it sits upright on a truck with its 1.0-m dimension in the direction of travel, and if the refrigerator cannot slide on the truck, how rapidly can the truck accelerate without tipping the refrigerator over?

II. Thermodynamics

1) The PV diagram in Fig. below shows two possible states of a system containing 1.45 moles of a monatomic ideal gas. ($P_1 = P_2 = 450 \text{ N/m}^2$, $V_1 = 2.00\text{m}^3$, $V_2 = 8.00\text{m}^3$).

- (a) Draw the process which depicts an isobaric expansion from state 1 to state 2 and label this process (A).
- (b) Find the work done by the gas and the change in internal energy of the gas in process (A).
- (c) Draw the process which depicts an isothermal expansion from state 1 to the volume V_2 followed by an isochoric increase in temperature to state 2 and label this two-step process (B).
- (d) Find the change in internal energy of the gas for the two-step process (B).



2) Estimate the maximum allowable pressure in a 38-cm- long cathode ray tube if 98 percent of all electrons must hit the screen without first striking an air molecule.

III. Electricity and Magnetism

1) Make a raw (order-of-magnitude estimate) of the maximum attainable electric field strength (breakdown field) in the air at normal conditions. What is the mechanism of the breakdown?

2) A circular metal disk of radius R rotates with angular velocity ω about an axis through its center perpendicular to its face. The disk rotates in a uniform magnetic field B whose direction is parallel to the rotation axis. Determine the emf induced between the center and the edges.

IV. Optics & Waves

1) The Doppler effect using ultrasonic waves of frequency $2.25 \times 10^6 \text{ Hz}$ is used to monitor the heartbeat of a fetus. A (maximum) beat frequency of 500 Hz is observed. Assuming that the speed of sound in tissue is $1.54 \times 10^3 \text{ m/s}$, calculate the maximum velocity of the surface of the beating heart.

2) An 80-mm-focal-length lens is used to focus an image on the film of a camera. The maximum distance allowed between the lens and the film plane is 120 mm. (a) How far ahead of the film should the lens be if the object to be photographed is 10.0 m away? (b) 3.0 m away? (c) 1.0 m away? (d) What is the closest object this lens could photograph sharply?

V. Mathematical Physics

1) Use Cauchy's theorem to evaluate the integral:

$$\oint_C \frac{\sin z}{2z - \pi} dz,$$

- (a) C is a the circle $|z| = 1$
- (b) C is a the circle $|z| = 2$.

2) In the partial differential equation

$$\frac{\partial^2 z}{\partial x^2} - 5 \frac{\partial^2 z}{\partial x \partial y} + 6 \frac{\partial^2 z}{\partial y^2} = 0$$

make a change a variables

$$\begin{aligned} s &= y + 2x, \\ t &= y + 3x. \end{aligned}$$

Solve the resulting equation for $z(s, t)$.

VI. Modern Physics

1) A negative muon traveling at 33 percent the speed of light collides head on with a positive muon traveling at 50 percent the speed of light. The two muons (each of mass $105.7 \text{ MeV}/c^2$) annihilate, and produce how much electromagnetic energy?

2) The proper life-time, measured in a reference frame where the particle is at rest, for tau-lepton is $2.91 \times 10^{-13} \text{ s}$. The rest mass of tau-lepton is $1777 \text{ MeV}/c^2$. If a tau-lepton is created with a kinetic energy of 450 MeV, how long would its track be as measured in the lab, on average, ignoring any collisions?