SOLUTIONS

PHYSICS PRACTICE PROBLEMS FOR NON-TECHNICAL MAJORS

CLASSICAL PHYSICS

FUNDAMENTAL DIMENSIONS

1. Give the units of mass density in the (a) MKS system of units; (b) CGS system of units.

(a) $\frac{kg}{m^3}$

(b) $\frac{g}{cm^3}$

UNIT CONVERSIONS

1. Given that q has units of coul, v has units of meters per second, B has units of $\frac{kg}{coul-sec}$, and $F = qvB\sin\theta$, determine the units of F.

$F = qvB\sin\theta$ Using only units, this gives:

$$[F] = (coul)(\frac{m}{sec})(\frac{kg}{coul \cdot sec})$$

$$[F] = \frac{kg\text{-}m}{sec^2} = Newton, (N)$$

2. The average speed of a sample of particles at $70^{\circ}F$ is $2.50x10^5 \frac{cm}{sec}$.

Convert to units of $\frac{ft}{hr}$.

$$\left(2.50x10^5 \frac{cm}{sec}\right)\left(\frac{3600\,sec}{hr}\right)\left(\frac{1in}{2.54\,cm}\right)\left(\frac{1ft}{12\,in}\right) = 2.9528x10^7 \frac{ft}{hr}$$

SCALAR AND VECTOR QUANTITIES

1. A submarine is traveling West at 15 knots. What is its speed, v? What is its velocity, $\vec{v}$?

$v = 15$ knots

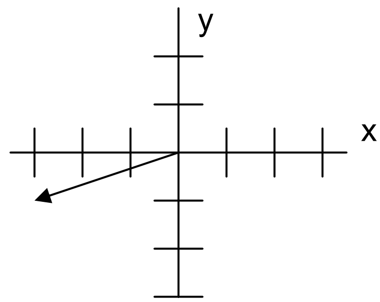
$\vec{v} = 15$ knots West

2. Can two objects traveling in opposite directions have equal accelerations? Explain.

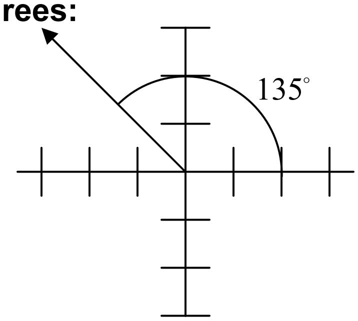
Yes. If an object's acceleration is in the same direction as its velocity, then its speed is increasing. If an object's acceleration is in the opposite direction as its velocity, then its speed is decreasing. For example, one object is thrown upward into the air while another is in falling downward. They both undergo the same magnitude and direction of acceleration due to gravity.

<u>VECTOR IDENTIFICATION</u>

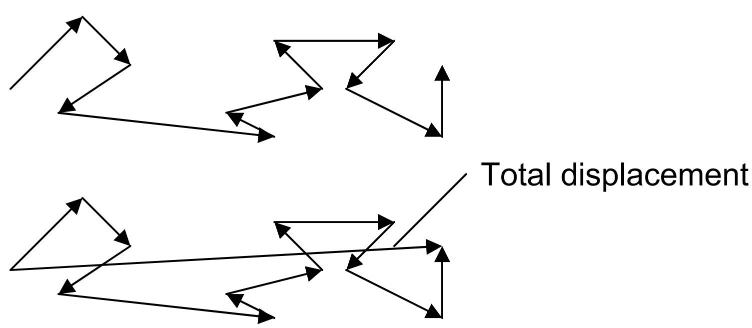
1. Sketch the vector (-3,-1):



2. Sketch a vector at 135 degrees:



3. A particle traveling through the atmosphere travels along the pathway below. Graphically represent the total displacement vector.



NEWTON'S LAWS OF MOTION

1. Using the fact that $g_{moon} = \frac{1}{6} g_{earth}$, find the weight on the moon of an object that weighs 200N on earth.

$$F = ma$$

$$F_{earth} = ma_{earth},\quad F_{moon} = ma_{moon}$$

$$m = \frac{F_{earth}}{a_{earth}} = \frac{F_{moon}}{a_{moon}}$$

$$F_{moon} = a_{moon}\left(\frac{F_{earth}}{a_{earth}}\right) = g_{moon}\left(\frac{F_{earth}}{g_{earth}}\right) = \left(\frac{1}{6}g_{earth}\right)\left(\frac{F_{earth}}{g_{earth}}\right) = \frac{F_{earth}}{6} = \frac{200N}{6} = 33.333N$$

MOMENTUM PRINCIPLES

1. A 50 g bullet is fired into a 2 kg wooden block. The initial speed of the bullet is 1500 mi/hr, and the block is initially at rest. What is the final speed of the block-bullet system just after impact?

$$P_o = P_f$$

$$m_{bullet}v_{bullet_o} + m_{block}\cancel{v}_{block_o} = \left(m_{bullet} + m_{block}\right)v_f$$

$$v_f = \frac{m_{bullet}v_{bullet_o}}{m_{bullet} + m_{block}} = \frac{50\,g\left(1500\,\frac{mi}{hr}\right)}{50\,g + 2000\,g} = 36.585\,\frac{mi}{hr}$$

2. If it took one tenth of a second for the bullet from problem 1 to embed itself in the wooden block, what average force was exerted on the block?

$$F = \frac{\Delta P}{\Delta t} = \frac{m_{block}v_{block_f} - m_{block}\cancel{v}_{block_o}}{0.1sec} = \frac{2\,kg\left(36.585\,\frac{mi}{hr}\right)}{0.1sec}\left(\frac{1hr}{3600\,sec}\right)\left(\frac{1609.3\,m}{1mi}\right)$$

$$F = 327.09\,\frac{kg-m}{sec^2} = 327.09\,N$$

3. What average acceleration did the block undergo?

$$F = ma$$

$$F_{block} = m_{block}a_{block}$$

$$a_{block} = \frac{F_{block}}{m_{block}} = \frac{327.09\,N}{2\,kg} = 163.55\,\frac{m}{sec^2}$$

4. Does this acceleration match the change in velocity of the block that we calculated in problem 1?

$$a = \frac{\Delta v}{\Delta t} = \frac{\left(36.585\,\frac{mi}{hr} - 0\,\frac{mi}{hr}\right)}{0.1sec}\left(\frac{1609.3\,m}{1\,mi}\right)\left(\frac{1\ hr}{3600\,sec}\right) = 163.55\,\frac{m}{sec^2}$$

Yes, it does match.

FORCE AND WEIGHT

1. What is the mass of an object that weighs 150 lbf on earth?

$$W = \frac{mg}{g_c}$$

$$m = \frac{g_c \cdot W}{g} = \frac{\left(32.17 \frac{\text{ft} - \text{lbm}}{\text{lbf} - \text{sec}^2}\right)(150 \text{ lbf})}{32.17 \frac{\text{ft}}{\text{sec}^2}} = 150 \text{ lbm}$$

2. What is the acceleration due to gravity on Planet X, if a 5000 lbm object weighs 20000 lbf there?

$$W = \frac{mg}{g_c}$$

$$g = \frac{g_c \cdot W}{m} = \frac{\left(\frac{32.17 \text{ ft} - \text{lbm}}{\text{lbf} - \text{sec}^2}\right)(20000 \text{ lbf})}{5000 \text{ lbm}} = 128.68 \frac{\text{ft}}{\text{sec}^2}$$

ENERGY AND WORK

1. A crane atop a 200m skyscraper accidentally drops a 2000 kg beam over the edge of the roof. What potential to do work does the beam have when it is level with the top of the building?

$$PE = mgz = (2{,}000 \text{ kg})\left(9.8 \frac{\text{m}}{\text{sec}^2}\right)(200 \text{ m}) = 3.92\text{x}10^6 \text{ J}$$

2. At some point during its fall, the beam from problem 1 has a kinetic energy of $1.96\text{x}10^6$ J. What is the speed of the beam at that point?

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2 \cdot KE}{m}} = \sqrt{\frac{2\ (1.96\text{x}10^6 \text{ J})}{2000 \text{ kg}}} = 44.272 \frac{\text{m}}{\text{sec}}$$

3. A man does 600 J of work on a desk as he pushes it 10 m across the floor. What average force did the man apply?

$$W = F \cdot d$$

$$F = \frac{W}{d} = \frac{600 \text{ J}}{10 \text{ m}} = 60 \text{ N}$$

LAW OF CONSERVATION OF ENERGY

1. A 10 kg object is thrown straight up with an initial velocity of 20 m/sec. How high does the object rise?

$$KE_o + \cancel{PE_o} + \cancel{E_{added}} = \cancel{KE_f} + PE_f + \cancel{E_{removed}}$$

$$\frac{mv_o^2}{2} = mgz_f$$

$$z_f = \frac{\cancel{m} \cdot v_o^2}{2 \cdot \cancel{m} \cdot g} = \frac{v_o^2}{2g} = \frac{\left(20\,\frac{m}{sec}\right)^2}{2\,(9.8\,\frac{m}{sec^2})} = 20.408\,m$$

2. Regarding the object in problem 1, at what height will its potential energy equal its kinetic energy?

When equal, $PE_f = KE_f$

$$\Rightarrow \cancel{m}gz_f = \frac{\cancel{m}v_f^2}{2}$$

$$z_f = \frac{v_f^2}{2g}$$

Also, $KE_o + \cancel{PE_o} + \cancel{E_{added}} = KE_f + PE_f + \cancel{E_{removed}}$

$$\Rightarrow KE_o = KE_f + PE_f$$

$$\Rightarrow \frac{\cancel{m}v_o^2}{2} = \frac{\cancel{m}v_f^2}{2} + \cancel{m}gz_f$$

$$v_f^2 = 2\left[\frac{v_o^2}{2} - gz_f\right]$$

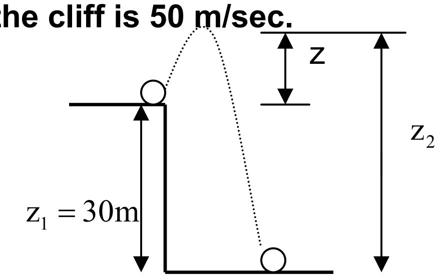
Combining,

$$z_f = \frac{v_f^2}{2g} = \frac{2\left[\frac{v_o^2}{2} - gz_f\right]}{2g} = \frac{v_o^2}{2g} - z_f$$

$$\Rightarrow 2z_f = \frac{v_o^2}{2g}$$

$$z_f = \frac{v_o^2}{4g} = \frac{\left(20\,\frac{m}{sec}\right)^2}{4 \cdot 9.8\,\frac{ft}{sec^2}} = 10.204\,m$$

3. An object is thrown upwards from a cliff of height 30m. The speed of the object at the bottom of the cliff is 50 m/sec.



Find the height, z, above the cliff that the object rises.

From the top of the throw to the bottom of the cliff:

$$\cancel{KE_{top}} + PE_{top} + \cancel{E_{added}} = KE_{bottom} + \cancel{PE_{bottom}} + \cancel{E_{removed}}$$

$$PE_{top} = KE_{bottom}$$

$$\cancel{m}gz_2 = \frac{\cancel{m}v_{bottom}^2}{2}$$

$$z_2 = \frac{v_{bottom}^2}{2g} = \frac{\left(50\,\frac{m}{sec}\right)^2}{2 \cdot 9.8\,\frac{m}{sec^2}} = 127.55\,m$$

$$z = z_2 - z_1 = 127.55\,m - 30\,m = 97.55\,m$$

4. Find the initial speed of the object in problem 3.

We already know that $PE_{top} = KE_{bottom} = \frac{mv_{bottom}^2}{2}$ and,

$$KE_o + PE_o + \cancel{E_{added}} = \cancel{KE_{top}} + PE_{top} + \cancel{E_{removed}}$$

$$\Rightarrow KE_o + PE_o = PE_{top} = KE_{bottom}$$

$$\frac{\cancel{m}v_o^2}{2} + \cancel{m}gz_1 = \frac{\cancel{m}v_{bottom}^2}{2}$$

$$v_o^2 = 2\left[\frac{v_{bottom}^2}{2} - gz_1\right]$$

$$v_o = \sqrt{v_{bottom}^2 - 2gz_1} = \sqrt{\left(50\,\frac{m}{sec}\right)^2 - 2\left(9.8\,\frac{m}{sec^2}\right)(30\,m)} = 43.726\,\frac{m}{sec}$$

POWER

1. Lube oil flows through an engine at a rate of 10 lbm/sec. The engine transfers 1000 BTU per lbm to the oil. What is the thermal power of (heat rejected by) the engine in $\frac{\textbf{BTU}}{\textbf{hr}}$?

$$\text{Thermal Power} = \frac{\text{Heat used}}{\text{Time required}} = \left(1000\frac{\text{BTU}}{\text{lbm}}\right)\left(10\frac{\text{lbm}}{\text{sec}}\right)\left(\frac{3600\,\text{sec}}{\text{hr}}\right) = 3.6\text{x}10^{7}\frac{\text{BTU}}{\text{hr}}$$

2. A pump operates at 250,000 W of mechanical power. Fluid flows through the pump at a rate of 250 kg/sec. What is the work done per kg of fluid flowing through the pump?

$$\frac{\text{Work}}{\text{kg}} = \frac{250{,}000\ \text{W}}{250\frac{\text{kg}}{\text{sec}}} = 1000\frac{\text{J}}{\text{kg}}$$

3. A 1500 kg empty elevator rises with a constant velocity of 20m/sec. The force generated by the elevator's motor is equal to the force of gravity on the elevator. What is the power of the motor in HP?

$$P = Fv = mgv$$

$$= (1500\text{kg})\left(9.8\frac{\text{m}}{\text{sec}^2}\right)\left(20\frac{\text{m}}{\text{sec}}\right) = 294000\frac{\text{kg}-\text{m}^2}{\text{sec}^3} = 294{,}000\ \text{W}\left(\frac{1\ \text{HP}}{745.7\ \text{W}}\right) = 394.26\,\text{HP}$$

NUCLEAR PHYSICS AND REACTOR THEORY

ATOMIC NATURE OF MATTER

1. Name the element, and give the atomic number, mass number, number of protons, number of neutrons, and number of electrons in the following nuclide: $^{135}_{53}$?

Name: On a periodic table, we can see that the element with Z=53 is iodine (I).
Atomic number: Z=53
Mass number: A=135
Protons: 53
Neutrons: A-Z=135-53=82
Electrons: 53

2. Describe the location of protons, neutrons, and electrons within an atom.

Protons and neutrons are located within the nucleus. Electrons are found outside the nucleus in the electron cloud.

3. Which force is responsible for holding a nucleus together? Describe it.
The nuclear force. It is strong (much stronger than the electrostatic force of repulsion between protons in a nucleus), attractive (holds nucleons together in the nucleus), short-ranged ($\sim 10^{-13}\,\text{cm}$), charge-independent (equally strong for proton-proton, proton-neutron, or neutron-neutron attraction), and saturable (due to short range, a nucleon can only attract a few of its nearest neighbors).

4. Define isotope.
Isotopes are nuclides that have the same atomic number and are therefore the same element, but differ in the number of neutrons.

CHART OF THE NUCLIDES

1. How many isotopes have an atomic mass number of 8?

5 (He-8, Li-8, Be-8, B-8, C-8)

2. What is the half-life of H-3?

12.3 a (12.3 years)

3. Calculate the atomic weight of boron. (B-10 has an isotopic mass of 10.0129372amu and B-11 has an isotopic mass of 11.0093056amu.)

$$\text{Atomic Weight} = 0.199(10.0129372\,\text{amu}) + 0.801(11.0093056\,\text{amu}) = 10.811\,\text{amu}$$

4. Define enriched uranium.

Enriched uranium is uranium in which the isotope uranium-235 has a concentration greater than its natural value of 0.7%.

MASS DEFECT AND BINDING ENERGY

1. What is the mass defect for U-238? (The mass of an U-238 atom is 238.050785amu.)

$$\Delta m = \left[Z\left(m_p + m_e\right) + \left(A - Z\right)m_n\right] - m_{atom}$$
$$= \left[92\left(1.007277\,\text{amu} + 0.000548597\,\text{amu}\right) + \left(238 - 92\right)\left(1.008665\,\text{amu}\right)\right] - 238.050785\,\text{amu}$$
$$= 1.93426\,\text{amu}$$

2. What is the binding energy for U-238?

$$\text{B.E.} = \Delta m\left(\frac{931.5\,\text{MeV}}{\text{amu}}\right) = \left(1.93426\,\text{amu}\right)\left(\frac{931.5\,\text{MeV}}{\text{amu}}\right) = 1801.8\,\text{MeV}$$

3. Which has the greater binding energy per number of nucleons: U-235 or U-238? (U-235 has a B.E.=1784 MeV.)

$$\text{U-235}: \quad \frac{\text{B.E.}}{\text{A}} = \frac{1784\,\text{MeV}}{235} = 7.5915\,\text{MeV per nucleon}$$

$$\text{U-238}: \quad \frac{\text{B.E.}}{\text{A}} = \frac{1801.8\,\text{MeV}}{238} = 7.5704\,\text{MeV per nucleon}$$

$\Rightarrow$ U-235 has the greater binding energy per nucleon.

4. (a) Find the combined mass of an electron, a proton, and a neutron that are far apart from each other.

$$m = m_p + m_n + m_e = (1.007277 + 1.008665 + 0.000548597)\,\text{amu} = 2.01649\,\text{amu}$$

(b) Compare this to the mass of a deuterium atom (2.01410178amu) and explain the difference.

The bound system is less massive because mass is converted into energy and released when the components become bound. The difference is the mass defect, Δm.

MODES OF RADIOACTIVE DECAY

1. Based on conservation laws, state whether the following reactions are possible or not. If not, indicate which conservation law or laws are violated.

(a) $^{12}_{6}\text{C} \rightarrow {}^{10}_{5}\text{B} + {}^{0}_{-1}\text{e} + \overline{\upsilon}$

Not possible: Conservation of charge and nucleons

(b) $^{0}_{-1}\text{e} + {}^{0}_{+1}\text{e} \rightarrow \text{nothing}$

Not possible: Conservation of energy

(c) $^{16}_{8}\text{O} + {}^{6}_{3}\text{Li} \rightarrow {}^{20}_{10}\text{Ne} + {}^{1}_{1}\text{H}$

Not possible: Conservation of nucleons

(d) $^{0}_{-1}\text{e} + {}^{0}_{+1}\text{e} \rightarrow 2\left[{}^{0}_{0}\gamma\right]$

Possible

2. Give the primary type of decay and the decay equation for C-11.

C-11 will undergo beta-plus decay:

$^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + {}^{0}_{+1}\text{e} + {}^{0}_{0}\upsilon$

3. Write the reaction equation for Ac-223 undergoing an alpha decay.

$^{223}_{89}\text{Ac} \rightarrow {}^{219}_{87}\text{Fr} + {}^{4}_{2}\text{He} + {}^{0}_{0}\gamma$

RADIOACTIVITY

1. A radioactive sample initially contains 100g of nuclide X-100. Nuclide X undergoes beta-minus decay into nuclide Y, which is stable. Initially, there are 1.7x10^{19} decays per second. What is the half-life of nuclide X?

$$A = \lambda N = \frac{\ln 2}{t_{1/2}} \cdot \frac{m \cdot N_A}{GAW} \Rightarrow t_{1/2} = \frac{\ln 2 \cdot m \cdot N_A}{GAW \cdot A} = \frac{(\ln 2)(100\,g)(6.02x10^{23})}{(100\,g)\left(\frac{1.7x10^{19}}{sec}\right)}$$

$$t_{1/2} = 24{,}545\,sec = 6.818\,hr$$

2. At what time is the activity of the sample in problem 1 equal to 1.7x10^{18} sec^{-1}?

$$A = A_o e^{-\lambda t}$$

$$\ln\left(\frac{A}{A_o}\right) = -\lambda t$$

$$t = \frac{\ln\left(\frac{A}{A_o}\right)}{-\lambda} = \frac{\ln\left(\frac{1.7x10^{18}\,sec^{-1}}{1.7x10^{19}\,sec^{-1}}\right)}{\frac{-\ln 2}{6.818\,hr}} = 22.65\,hr$$

3. A certain nuclide is produced at a constant rate of 10^{10} atoms per second, and has a half-life of 2 days. What number of atoms is present at equilibrium?

$$R = \lambda N$$

$$N = \frac{R}{\lambda} = \frac{10^{10}\,\frac{atoms}{sec}}{\left(\frac{\ln 2}{2\,d}\right)\left(\frac{1\,d}{24\,hr}\right)\left(\frac{1\,hr}{3600\,sec}\right)} = 2.4930x10^{15}\,atoms$$

4. What is the activity in Curies at equilibrium for the nuclide in problem 3?

$$A = \lambda N = R = \left(10^{10}\,\frac{decays}{sec}\right)\left(\frac{1\,Curie}{3.7x10^{10}\,\frac{decays}{sec}}\right) = 0.27027\,Curies$$

NEUTRON INTERACTIONS

Note: Conservation laws still apply.

1. A neutron elastically scatters with an H-1 nucleus. Write the complete reaction equation.

$${}_0^1n + {}_1^1H \rightarrow {}_1^1H + {}_0^1n$$

2. O-16 absorbs a neutron, and a proton is emitted. Name the type of reaction, and write the reaction equation.

Particle ejection

$$ {}_0^1n + {}_8^{16}O \rightarrow \left({}_8^{17}O\right)^* \rightarrow {}_7^{16}N + {}_1^1p $$

3. B-10 absorbs a neutron, and a gamma is emitted. Name the type of reaction, and write the reaction equation.

Radiative capture

$$ {}_0^1n + {}_5^{10}B \rightarrow \left({}_5^{11}B\right)^* \rightarrow {}_5^{11}B + {}_0^0\gamma $$

4. Name the type of reaction: $ {}_0^1n + {}_8^{16}O \rightarrow \left({}_8^{17}O\right)^* \rightarrow {}_8^{16}O + {}_0^1n + {}_0^0\gamma $

Inelastic scattering.

NUCLEAR FISSION

1. Define critical energy.

The critical energy (E_{crit}) is the minimum excitation energy required for fission to occur.

2. What KE must a neutron have to make fission probable in U-238?

Require $\Delta BE + KE \geq E_{crit}$

From table 4, we see that $\Delta BE = 5.5\,MeV$ and $E_{crit} = 7.0\,MeV$

$\Rightarrow KE \geq 1.5\,MeV$

3. Explain the difference between fissile and fissionable materials.

In fissile material, fission is possible with neutrons of any energy level. Fissionable materials are materials in which fission is possible (including fissile materials). However, for some fissionable materials, fission is only possible with high energy neutrons.

4. Briefly describe the liquid drop model for fission.

In the liquid drop model, when a neutron is absorbed, a compound nucleus is formed. If the neutron was of sufficient energy, it may cause the compound nucleus to form a dumbbell shape. At that time, the electrostatic force of repulsion between the protons in the two parts of the dumbbell is strong, while the nuclear force of attraction between the two parts of the dumbbell is weakened due to its short range. If the repulsive forces exceed the attractive forces, the two parts of the dumbbell split apart and fission occurs.