

I. Multiple choice -- circle the one best answer.

4a; 5c; 8c

2. A ball is dropped off the roof of a building. It hits the ground in 2 seconds.

a) How tall is the building?

$$h = \frac{1}{2} g t^2 = 0.5 \times 9.8 \text{ (m/s}^2\text{)} \times 4 \text{ s}^2 = 19.6 \text{ m}$$

b) What is the vertical speed of the ball just before it hits the ground?

$$v = g t = 9.8 \text{ (m/s}^2\text{)} \times 2 \text{ s} = 19.6 \text{ m/s}$$

(this formula is true for constant acceleration = g)

A second ball is thrown **horizontally** from the roof, with a horizontal velocity of 20 m/sec.

c) How long does the ball take to reach the ground?

2 seconds (because the horizontal motion is independent of the vertical)

d) How far from the building (the horizontal distance) does it land?

$$v(\text{horizontal}) t = 20 \text{ (m/s)} \times 2 \text{ s} = 40 \text{ m}$$

3. An Israeli intermediate range missile is launched from a launching tube on the ground and travels to a target in Iraq 1000 Km away in 10 minutes. Assume the missile achieves its burnout velocity by the time it leaves its launching tube (i.e. thereafter there is no further rocket fuel). Ignore the curvature of the earth.

a) What is the missile's horizontal velocity (in units of m/sec or Km/sec)?

$$v(\text{horiz}) = 1000 \text{ Km} / (10 \text{ min} \times 60 \text{ (s/min)}) = 1.7 \text{ Km/s}$$

b) How long will the missile take to reach the highest point on its trajectory?

How does that compare with the time it takes to fall from its highest point to the target?

Total time is the 10 minutes. In half that it reaches highest point and in other half it falls to ground. There is a time symmetry.

So 5 min to reach high point.

c) How high does the missile go above the ground? The atmosphere is approximately 100 Km high. Does the rocket leave the atmosphere?

In 5 minutes it reaches high point and in the next 5 min (=300 s) it falls.

So use

$$h = \frac{1}{2} g t^2 = 0.5 \times 9.8 \text{ (m/s}^2\text{)} \times (300 \text{ s})^2 = 440 \text{ Km}$$

(Yes, this is above atmosphere.)

d) What is the **vertical** velocity as the missile nears the end of its range?

Again this is like any free falling object

$$v(\text{vert}) = g t = 9.8 \text{ (m/s}^2\text{)} \times 300 \text{ s} = 2900 \text{ m/s} = 2.9 \text{ Km/s}$$

e) An interceptor rocket is aimed at a point, the interception point, near the end of the incoming missile's trajectory. Suppose the payload of the incoming rocket is 2 meters long. For what approximate time period will the payload pass through the interception point?

A 2 m long rocket traveling at 2900 m/s passes a point in

$$2 \text{ m} / 2900 \text{ (m/s)} = 6.9 \times 10^{-4} \text{ s} = 0.69 \text{ millisecond}$$

4. Suppose a *hypothetical* Medford reactor had an accident one year after it was put into operation. It released various radionuclides into the area. You are going to estimate how much ^{239}Pu (Plutonium) could have been released had the reactor vessel been breached. Medford produces 420 MegaWatts of electrical power. Recall that **power** is the rate at which energy is produced: 1 Watt = 1 Joule/sec.

a) How much electrical energy is produced by the Medford reactor in one year (in units of Joules)?

$$420 \times 10^6 \text{ J/sec} \times 32 \times 10^6 \text{ sec} = 1.30 \times 10^{16} \text{ J}$$

b) Express the electrical energy released in one year (part a.) in units of MeV.

$$1.30 \times 10^{16} \text{ J} / (1.60 \times 10^{-13} \text{ J/MeV}) = 8.14 \times 10^{28} \text{ MeV}$$

c) Each fission reaction in the reactor core, involving ^{235}U , releases about 200 MeV. How many fission reactions are necessary to produce the requisite electrical energy (part b.), assuming that the Medford reactor has an efficiency of 20% (i.e. 20% of the total energy released gets converted to electrical energy).

Because of the 20% efficiency the amount of energy that needs to be produced is much greater, $8.14 \times 10^{28} \text{ MeV} / 0.20 = 4.07 \times 10^{29} \text{ MeV}$. Number of fissions will be $4.07 \times 10^{29} \text{ MeV} / 200 \text{ MeV} = 2.04 \times 10^{27}$ reactions.

d) If each fission reaction leads to an average of 2.5 neutrons and 1.7 of the resulting neutrons get absorbed by ^{238}U to form ^{239}Pu , how many ^{239}Pu nuclei are formed in one year? One fission leads to 1.7 Pu nuclei. So 2.04×10^{27} fissions lead to $1.7 \times 2.04 \times 10^{27} = 3.46 \times 10^{27}$ Pu nuclei produced.

e) What is the activity in Curies of that amount of Plutonium? The half life of ^{239}Pu is 24,400 years.

$$24,400 \text{ yr} \times 32 \times 10^6 \text{ sec/yr} = 7.81 \times 10^{11} \text{ sec.}$$

So Activity = $(0.69 / [7.81 \times 10^{11} \text{ sec}]) \times 3.46 \times 10^{27} = 3.1 \times 10^{15} \text{ dis/sec}$
and $(3.1 \times 10^{15} \text{ dis/sec}) / (3.7 \times 10^{10} \text{ dis/sec/Ci}) = 84,000 \text{ Ci}$

f) What is the mass of ^{239}Pu formed in one year?

$$3.46 \times 10^{27} \text{ Pu nuclei} \times (0.239 \text{ Kg/mole}) / (6.0 \times 10^{23} \text{ nuclei/mole}) = 1400 \text{ Kg.}$$