Chapter 1: Introduction

1-16) The value g = 9.81 m/s^2 is specific to the force of gravity on the surface of the earth. The universal formula for the force of gravitational attraction is:

$$F = G\frac{m_1 m_2}{r^2}$$

Where m_1 and m_2 are the masses of the two objects, r is the distance between the centers of the two objects, and G is the universal gravitation constant, G = 6.674×10^{-11} N(m/kg)^2.

A) Research the diameters and masses of the Earth and Jupiter.
B) Demonstrate that $F = m(9.81 \text{ m/s}^2)$ is a valid relationship on the surface of the earth.
C) Determine the force of gravity acting on a 1000 kg satellite that is 2000 miles above the surface of the Earth.
D) One of the authors of this book has a mass of 200 lb_m. If he was on the surface of Jupiter, what gravitational force in lb_f would be acting on him?

Solution:

A) Measurements obtained from different sources will vary slightly.

D_{Earth}~ 12,742 km $D_{Jupiter}$~ 142,000 km

$Mass_{earth}$= 5.97×10^{24} kg $Mass_{jupiter}$= 1.90×10^{27} kg

B) $Mass_{earth}$= 5.97×10^{24} kg $Radius_{Earth}$= 6.371×10^{6} meters

$$F = G\frac{m_1 m_2}{r^2} \rightarrow F = m_{object}\left(6.674 \times 10^{-11}\frac{\text{Nm}^2}{\text{kg}^2}\right)\frac{(5.97\times10^{24}\text{kg})}{(6.37\times10^{6}\text{ m})^2}\left(\frac{\left(\frac{\text{kg m}}{\text{sec}^2}\right)}{(1\text{ N})}\right)$$

$$\rightarrow \mathbf{F = m(9.81\frac{m}{sec^2})}$$

C) 2000 miles = 3218.68 km = 3218680 m

$$F = 1000\text{kg}\left(6.674 \times 10^{-11}\frac{\text{Nm}^2}{\text{kg}^2}\right)\frac{(5.97\times10^{24}kg)}{(6371000m+3218680m)^2} = \mathbf{4348\ N}$$

D) $Radius_{Jupiter}$= 66854000 m $Mass_{Jupiter}$= 1.898 × 10^{27} kg 200lb_m = 90.7 kg

$$F = 90.7\text{ kg}\left(6.674 \times 10^{-11}\frac{\text{Nm}^2}{\text{kg}^2}\right)\frac{(1.90\times10^{27}\text{kg})}{(7.10\times10^{7}\text{ m})^2}\left(\frac{\left(\frac{\text{kg m}}{\text{sec}^2}\right)}{(1\text{ N})}\right) = \mathbf{2281\ N}$$

1-17) A gas at *T*=300 K and *P*=1 bar is contained in a rigid, rectangular vessel that is 2 meters long, 1 meter wide and 1 meter deep. How much force does the gas exert on the walls of the container?

Solution:

1 Bar = 100,000 Pa

$$\text{Area}_{\text{Surface}} = (2\times\text{W}\times\text{H}) + (2\times\text{W}\times\text{L}) + (2\times\text{H}\times\text{L})$$

$$\text{Force} = \text{Pressure} \times \text{Area}$$

$$\text{Force} = (100000\text{Pa})(2\times1\text{m}\times1\text{m} + 2\times1\text{m}\times2\text{m} + 2\times1\text{m}\times2\text{m})\left(\frac{\left(\frac{\text{N}}{\text{m}^2}\right)}{\text{Pa}}\right)$$

$$\text{Force} = \mathbf{1\times10^6 N}$$

1-18) A car weighs 3000 lb_m, and is travelling 60 mph when it has to make an emergency stop. The car comes to a stop 5 seconds after the brakes are applied.

A) Assuming the rate of deceleration is constant, what force is required?
B) Assuming the rate of deceleration is constant, how much distance is covered before the car comes to a stop?

Solution:

A) $\text{Force} = \text{mass}\times\text{acceleration}$ $60\text{mph}\left(\frac{1\text{hr}}{3600\text{sec}}\right)\left(\frac{5280\text{ft}}{1\text{mile}}\right) = 88\frac{\text{ft}}{\text{sec}}$

$$\text{Acceleration} = \frac{\text{velocity}_{\text{final}} - \text{velocity}_{\text{initial}}}{\text{time}}$$

$$\text{a} = \frac{88\frac{\text{ft}}{\text{sec}} - 0}{5\text{ sec}}$$

$$\text{a} = 17.6\frac{\text{ft}}{\text{sec}^2}$$

$$\text{Force} = 17.6\ \frac{\text{ft}}{\text{sec}^2} \times 3000\text{lb}_\text{m}$$

$$\text{Force} = \mathbf{52500}\frac{\mathbf{lb_m ft}}{\mathbf{sec^2}}$$

B) $\text{Position}_\text{final} = \frac{\text{acceleration}*\text{time}^2}{2} + \text{velocity}_\text{inital} \times \text{time} + \text{position}_\text{intial}$

$$\text{Position}_\text{final} = \frac{\left(-17.6\frac{\text{ft}}{\text{sec}^2}\right)(5\text{sec})^2}{2} + \left(88\,\frac{\text{ft}}{\text{sec}}\right)(5\text{sec}) + 0$$

$$\text{Position}_\text{final} = \mathbf{220\ ft}$$

1-19) Solar panels are installed on a rectangular flat roof. The roof is 15 feet by 30 feet, and the mass of the panels and framing is 900 lb_m.

A) Assuming the weight of the panels is evenly distributed over the roof, how much pressure does the solar panel array place on the roof?
B) The density of fallen snow varies; here assume its ~30% of the density of liquid water. Estimate the total pressure on the roof if 4 inches of snow fall on top of the solar panels.

Solution:

A) $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ $\quad \text{Area} = \text{Length} \times \text{Width} \qquad \text{Force} = \text{Mass} \times \text{Acceleration}$

$$\text{Pressure} = \frac{(900\text{lb}_\text{m})\left(32.2\,\frac{\text{ft}}{\text{sec}^2}\right)}{(15\text{ft})(30\text{ft})}\left(\frac{1\text{lb}_\text{f}}{32.2\,\frac{\text{lb}_\text{m}\text{ft}}{\text{sec}^2}}\right)$$

$$\text{Pressure} = \mathbf{2}\,\frac{\mathbf{lb_f}}{\mathbf{ft^2}}$$

B) $\text{Density}_\text{snow} = (30\%)63.3\,\frac{\text{lb}_\text{m}}{\text{ft}^3} = 19.0\,\frac{\text{lb}_\text{m}}{\text{ft}^3}$

$$\text{Force}_\text{snow} = \text{Volume}_\text{snow} \times \text{Density}_\text{snow} \times \text{gravity}$$

$$\text{Pressure} = \frac{\text{Force}_\text{snow} + \text{Force}_\text{panels}}{\text{Area}}$$

$$4\text{inches} = 0.333\text{ft}$$

$$\text{Pressure} = \frac{\left((900\text{lb}_\text{m})\left(32.2\frac{\text{ft}}{\text{sec}^2}\right)\right) + \left((15\text{ft})(30\text{ft})(0.333\text{ft})\right)\left(19.0\frac{\text{lb}_\text{m}}{\text{ft}^3}\right)\left(32.2\frac{\text{ft}}{\text{sec}^2}\right)}{(15\text{ft})(30\text{ft})}\left(\frac{1\text{lb}_\text{f}}{32.2\frac{\text{lb}_\text{m}\text{ft}}{\text{sec}^2}}\right)$$

$$\text{Pressure} = \mathbf{8.33\frac{lb_f}{ft^2}}$$

1-20) A box has a mass of 20 kg, and a building has a height of 15 meters.

A) Find the force of gravity acting on the box.
B) Find the work required to lift the box from the ground to the roof of the building.
C) Find the potential energy of the box when it is on the roof of the building.
D) If the box is dropped off the roof of the building, find the kinetic energy and velocity of the box when it hits the ground.

Solution:

A) $\text{Force} = (20\text{kg})\left(9.81\frac{\text{m}}{\text{sec}^2}\right) = \mathbf{196.2\ N}$

B) $\text{Work} = \text{Force} \times \text{Distance}$

$\text{Work} = (196.2\text{N})(15\text{m}) = \mathbf{2943Nm = 2943\ J}$

C) $\text{Potential Energy} = \text{Mass} \times \text{Height} \times \text{Gravity}$

$\text{Potential Energy} = (20\text{kg})(15\text{m})\left(9.81\frac{\text{m}}{\text{sec}^2}\right) = \mathbf{2943Nm = 2943\ J}$

D) We know that Energy is conserved, so if the box is dropped from a height of 15 meters, its Kinetic Energy at Height = 0 meters will be the same as its potential energy at Height = 15 meters.

$$\text{Kinetic Energy} = \mathbf{2943Nm}$$

To find the object's velocity as it hits the ground:

$\text{Kinetic Energy} = \left(\frac{1}{2}\right)\text{Mass} \times \text{Velocity}^2$

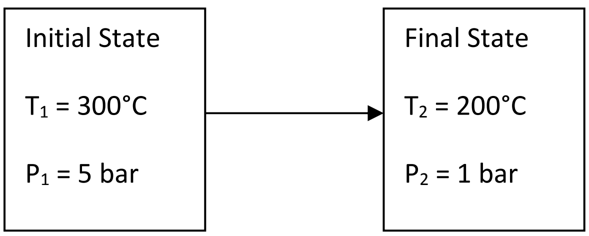
$2943\text{Nm} = \left(\frac{1}{2}\right)(20\text{kg}) \times \text{V}^2$

$$\left(294.3\frac{\text{Nm}}{\text{kg}}\right)\left(\frac{\frac{\text{kg m}}{\text{sec}^2}}{1\text{N}}\right) = 294.3\left(\frac{\text{m}^2}{\text{sec}^2}\right) = \text{V}^2$$

$V = \mathbf{17.16} \dfrac{\mathbf{m}}{\mathbf{sec}}$

1-21) 100 kg of steam is enclosed in a piston-cylinder device, initially at 300°C and 5 bar. It expands and cools to 200°C and 1 bar.

A) What is the change in internal energy of the steam in this process?
B) If the external pressure is constant at 1 bar, how much work was done by the steam on the surroundings?
C) Research and briefly describe at least two examples of machines, either historical or currently in use, that harness the energy in steam and convert it into work. Any form of work is acceptable; you needn't confine your research to expansion work (which was examined in parts A and B).



Solution:

Define the gas as the system.

A) From steam tables:

$$\hat{U}_1 = 2803.2 \ \frac{\text{kJ}}{\text{kg}}$$

$$\hat{U}_2 = 2658.2 \ \frac{\text{kJ}}{\text{kg}}$$

So $\Delta U = M\left(\hat{U}_2 - \hat{U}_1\right) = (100\ kg)\left(2658.2 - 2803.2\ \frac{\text{kJ}}{\text{kg}}\right) = \mathbf{-14,500\ kJ}$

B) From steam tables:

$$\hat{V}_1 = 0.5226 \frac{\text{m}^3}{\text{kg}}$$

$$\hat{V}_2 = 2.1724 \frac{\text{m}^3}{\text{kg}}$$

Thus the gas expands, and work is described by equation 1.22:

$$W_{EC} = -\int PdV$$

Pressure opposing the motion is constant at 1 bar, so:

$$W_{EC} = -P(V_2 - V_1) = -MP(\hat{V}_2 - \hat{V}_1)$$

$$W_{EC} = -(100\ kg)(1\ bar)\left(2.1724 - 0.5226\ \frac{\text{m}^3}{\text{kg}}\right)\left(\frac{10^5\ \text{Pa}}{\text{bar}}\right)\left(\frac{1\ \frac{\text{N}}{\text{m}^2}}{\text{Pa}}\right)\left(\frac{1\ \text{J}}{\text{Nm}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right)$$

$$= \mathbf{-16,498\ kJ}$$

The negative sign indicates work is transferred from gas to the surroundings.

C) Steam power is still used in electrical generators that run on the Rankine cycle with water as the operating fluid. Historically, steam engines have been used to power systems like pumps, boats, trains, sawmills etc. The common feature in these machines is they require shaft work that can be supplied by steam turbines.

1-22) A) An object is dropped from a height of 20 feet off the ground. What is its velocity when it hits the ground?

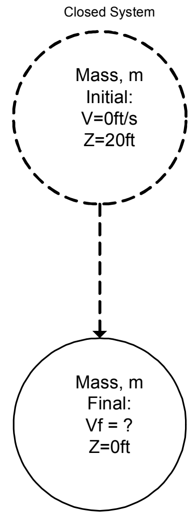
B) Instead of being dropped, the object is thrown down, such that when it is 20 feet off the ground, it already has an initial velocity of 20 ft/sec straight down. What is its velocity when it hits the ground?

C) What did you assume in answering questions A and B? Give at least three examples of objects for which your assumptions are very good, and at least one example of an object for which your assumptions would fail badly.

Solution:

A)

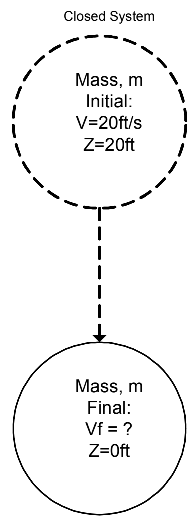
Energy is conserved, so ΔPE + ΔKE =0:



$$mg\Delta z + \frac{m\Delta v^2}{2} = 0$$
$$\frac{\Delta v^2}{2} = -g\Delta z$$
$$0.5\left(v_2^2 - v_1^2\right) = -g\left(z_2 - z_1\right)$$
$$v_1 = 0, z_2 = 0, so:$$
$$v_2 = \sqrt{2gz_1}$$
$$v_2 = \sqrt{(2)\left(\frac{32.2\,ft}{s^2}\right)(20\,ft)} = 35.9\,ft/s$$

B)

Energy is conserved, ΔPE + ΔKE =0:



$$mg\Delta z + \frac{m\Delta v^2}{2} = 0$$
$$g\Delta z + \frac{\Delta v^2}{2} = 0$$
$$\frac{v_2^2}{2} - \frac{v_1^2}{2} = g\left(z_1 - z_2\right)$$
$$v_2^2 = 2g\left(z_1 - z_2\right) + v_1^2, z_2 = 0$$
$$v_2 = \sqrt{2g\left(z_1 - z_2\right) + v_1^2}$$
$$v = \sqrt{2(32.2\,ft/s^2)(20\,ft) + (20)^2\,ft^2/s^2} = 41.1\,ft/s$$

C) Air resistance was ignored. This is reasonable for most objects, but wouldn't work for something with a high surface area to mass ratio, such as a piece of paper or a feather.

1-23) An airplane is 20,000 feet above the ground when a 100 kg object is dropped from it. If there were no such thing as air resistance, what would the vertical velocity and kinetic energy of the dropped object be when it hits the ground?

Solution:

Energy is conserved, so ΔPE + ΔKE =0:

$$mg\Delta z + \frac{m\Delta v^2}{2} = 0$$

$$\frac{\Delta v^2}{2} = -g\Delta z$$

$$0.5\left(v_2^2 - v_1^2\right) = -g\left(z_2 - z_1\right), v_1 = 0, z_2 = 0$$

$$v_2 = \sqrt{2gz_1}$$

$$v_2 = \sqrt{(2)\left(\frac{32.2\,ft}{s^2}\right)(20000\,ft)} = 1135\,ft/s$$

$$K.E. = \frac{mv^2}{2} = \frac{(100kg)(1135\,ft/s)^2}{2}\left(\frac{0.3048m}{1ft}\right)^2\left(\frac{1N}{1kgm/s^2}\right)\left(\frac{1J}{Nm}\right) = 5.984\times10^6\,J$$

K.E.* = 5.984×10⁶ *J

1-24) A filtration system continuously removes water from a swimming pool, passes the water through filters and then returns it to the pool. Both pipes are located near the surface of the water. The flow rate is 15 gallons per minute. The water entering the pump is at 0 psig, and the water leaving the pump is at 10 psig.

A) The diameter of the pipe that leaves the pump is 1 inch. How much flow work is done by the water as it leaves the pump and enters the pipe?
B) The water returns to the pool through an opening that is 1.5 inches in diameter, located at the surface of the water, where the pressure is 1 atm. How much work is done by the water as it leaves the pipe and enters the pool?
C) "The system" consists of the water in the pump and in the pipes that transport water between the pump and the pool. Is the system at steady state, equilibrium, both, or neither?

Solution:

A) $\dot{\text{Work}}_{\text{flow}} = \text{Pressure} \times \dot{\text{Volume}}$

Convert gauge pressure into absolute.