Part 1

Short Questions:

1. (4 pts) Two cranes are each loading cargo onto a boat from the same dock. The first crane’s engine has twice the horsepower of the second; is it correct to conclude that 1st crane does double the work of the 2nd? Qualitatively explain your answer (i.e. a little more than simply “yes” or “no”).

2. (5 pts) A blob of mass $m$ attached to an elastic with a spring constant $k$ oscillates with a period $T$. Decide how the frequency would change if the blob was replaced with one twice as massive: $2\times$ longer, $\sqrt{2}\times$ longer, $\sqrt{2}\times$ shorter, or $2\times$ shorter.

3. (5 pts) If I tell you a simple harmonic oscillator’s position as a function of time is $x(t) = 5 \cos(2\pi t)$ cm, explain how you know the following graph does not describe it’s velocity.

![Graph of x(t) vs. t with velocity curve shown]

4. (6 pts) Referring to the figure below, show that the centre of mass of the Sun-Jupiter-Neptune system is at $x = 9.72 \times 10^8$ km (which, incidentally, is outside the Sun’s radius of $6.96 \times 10^8$ km). Which has the bigger effect on shifting the centre-of-mass, smaller Neptune which is farther away, or massive Jupiter which is much closer to the Sun?

![Diagram of solar system with masses and distances labeled]

$M_S = 1.99 \times 10^{33}$ kg
$M_J = 1.90 \times 10^{27}$ kg
$M_N = 1.02 \times 10^{26}$ kg

$x = 0 \quad x = 7.78 \times 10^8$ km

$x = 4.50 \times 10^9$ km
Part 2

Problem 1 (20 pts) *Satellite motion:*

On Weds, Feb 20 2008 at 7:26 p.m. PST, the USS Lake Erie fired a $9.5M$ SM-3 missile at a nonfunctioning National Reconnaissance Office satellite 153 miles above the Pacific Ocean.

(a) Given that the satellite had a mass of 2270 kg, what was the gravitational force the Earth had on the satellite? What force did the satellite have on the Earth?

Ans: __________________________

(b) If you approximate the orbit of the satellite as circular (knowing full-well that it wasn’t since its orbit was quickly deteriorating), what was its speed (in km/hr) when orbiting the Earth?

Ans: __________________________

(c) Communication satellites are set in orbit such that they remain in the same position above the Earth. This is called a *geostationary* orbit, i.e. it circles the Earth at the same rate the Earth rotates at. How much higher above the Earth would the NRO satellite have had to have been to be in a geostationary orbit?

Ans: __________________________
Problem 2  (20 pts) Simple harmonic motion:

A 2 kg frictionless block is attached to an ideal spring with force constant 350 N/m. Initially, the block has a velocity of −3 m/s at a displacement of +0.3 m. Find:

(a) the amplitude of motion

Ans: ____________________________

(b) the maximum acceleration of the block

Ans: ____________________________

(c) the maximum force the spring exerts on the block

Ans: ____________________________

(d) the angular frequency of its motion

Ans: ____________________________
Problem 3 (20 pts) Work-energy theorem:

A child playing with a 60 g raquetball on his parent’s second-story apartment has a tantrum and throws it straight down towards the ground with an initial speed of 1.5 m/s. The height of the ball when it left his hand was 8 m above the ground.

(a) What is the total initial energy of the ball, i.e. when it leaves his hand?

Ans: __________________________

(b) If the ball loses 30% of its energy with each bounce, what will be its maximum height after the third bounce?

Ans: __________________________

(c) How many bounces before the ball will only reach a height of 1.36 m?

Ans: __________________________
Problem 4  (20 pts) Conservation of linear momentum:

I was playing pool at Fast Eddies and was down to the 150 g 8-ball. I shot the 170 g cue ball, which was initially lined up in \( \hat{x} \) with the 8-ball, giving it an initial velocity of 10 ft/s. The figure below depicts how after the collision, the 8-ball was going 7.52 ft/s in a direction \(-45^\circ\) relative to the \( \hat{x} \)-direction. In what follows, neglect friction and ‘english’ (spin) of the balls; treat them as point-like particles.

(a) What was the velocity (speed and direction!) of the cue ball after the collision?

Ans: ____________________________

(b) Was this an elastic or inelastic collision?

Ans: ____________________________

(c) If the pockets are 0.25" bigger than the diameter of the balls, did I win the game (according to Canadian rules)?

Ans: ____________________________

*If you ‘sewer’ – or sink the cue ball – after hitting the 8-ball, you automatically lose.
Formulae

\[ ax^2 + bx + c = 0 \quad \Rightarrow \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

\[ h_a = h \cos \theta \quad h_o = h \sin \theta \quad \tan \theta = \frac{h_o}{h_a} \]

\[ \Delta \vec{r} = \vec{r}_{\text{final}} - \vec{r}_{\text{initial}} = (\Delta r_x) \hat{x} + (\Delta r_y) \hat{y} = (\Delta x) \hat{x} + (\Delta y) \hat{y} = (x(t) - x_o) \hat{x} + (y(t) - y_o) \hat{y} \]

\[ \vec{v}(t) = \vec{v}_o + \vec{a} t + \frac{1}{2} \vec{a} t^2 \]

\[ \vec{v}_f = \vec{v}_o + \vec{a} \Delta \vec{r} \]

\[ \Delta \vec{x} = \frac{1}{2} (v_i + v_f) t \]

\[ v_{\text{tangential}} = \frac{2 \pi R}{T} \quad a_{\text{radial}} = \frac{v_{\text{tangential}}^2}{R} \quad F_{\text{gravity}} = G \frac{m_1 m_2}{r_{12}^2} \quad m g = G m M \frac{1}{R^2} = m \frac{v_{\text{tangential}}^2}{R} \]

\[ W = |\vec{F}| \cos \theta |\Delta s| \]

\[ P = \frac{\Delta W}{\Delta t} \quad W_{\text{tot, f}} = W_{\text{tot, i}} + W_{\text{other}} \quad K_f + U_{\text{grav, f}} + U_{\text{elas, f}} = K_i + U_{\text{grav, i}} + U_{\text{elas, i}} + W_{\text{other}} \]

\[ \langle P \rangle = |\vec{F}| \cos \theta \langle \vec{v} \rangle \]

\[ x(t) = A \cos \omega t \quad \omega = \frac{2 \pi f}{T} \]

\[ v(t) = -A \omega \sin \omega t \quad T_{\text{pendulum}} = 2 \pi \sqrt{L/g} \]

\[ a(t) = -A \omega^2 \cos \omega t \quad T_{\text{spring}} = 2 \pi \sqrt{m/k} \]

\[ M \vec{a}_{\text{cm}} = m_1 \vec{a}_1 + m_2 \vec{a}_2 + \ldots + m_N \vec{a}_N = \sum \vec{F}_{\text{external}} \quad \sum \vec{F}_{\text{internal}} = 0 \]

\[ \langle \vec{F} \rangle t = \Delta \vec{p} \quad M \vec{v}_{\text{cm}} = \vec{p}_{\text{cm}} = m_1 \vec{v}_1 + m_2 \vec{v}_2 + \ldots + m_N \vec{v}_N \quad \sum \vec{F}_{\text{external}} = 0 \iff \vec{p}_{\text{cm}} = \text{constant} \]

Constants/Conversions

\[ g = 9.80 \text{ m/s}^2 = 32.15 \text{ ft/s}^2 \text{ (on surface of Earth)} \]

\[ G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \]

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\[ 1 \text{ revolution} = 360^\circ = 2 \pi \text{ radians} \]