PHYS 1210 Spring 2026 Exam 2

Brief Solutions

1. Descending lunar lander

We are told that the lander's weight with crew is 16,000 newtons. From this we deduce that the Moon pulls on the lander with a force of 16,000 newtons, toward the center of the Moon. By Newton's third law, that means that the lander pulls upward (toward the lander) on the Moon with a force of 16.000 newtons.

2. Work is a scalar

Work is a dot product of a force vector with a displacement vector. Dot products of vectors are scalars.

3. Speeding train

A. Initial kinetic energy

$$1/2mv^2 = 1/2\,(40\,\text{kg})(25.0\,\text{m/s})^2 = 12.5\,\text{MJ}$$

B. Work done by Superman

Superman stopped the train. By the work-energy theorem, the work done equals the change in kinetic energy. The change in kinetic energy is $-12.5\,\text{MJ}$, so the work Superman did on the train was $-12.5\,\text{MJ}$.

C. Sign of work

This is just to be certain you got this concept. The kinetic energy *decreased*, so the work done was *negative*.

D. Magnitude of Superman's push

Superman pushed the train against its velocity, so the force $\vec{F}$ and displacement $\vec{s}$ were in opposite directions. Thus, the work was $W = \vec{F}\cdot\vec{s} = -Fs$. Thus $F = -W/s = (12.5\,\text{MJ})/(65.0\,\text{m}) = 192\times10^3\,\text{N}$.

E. Was power constant?

No. There are several ways to think about this. Power is the rate of doing work, that is, the rate of changing energy. With a constant force, the train's *velocity* changed at a constant rate. But its kinetic energy is proportional to the *square* of its speed. The square of the speed, and thus the kinetic energy, changes more slowly as time passes. Thus, the power decreases.

A more quantitative way to think about this is to use the formula that power is the dot product of force with velocity, $\vec{F}\cdot\vec{v}$. Thus, as the speed decreases and the force stays constant, the power decreases.

4. Throwing a baseball

It isn't reasonable for the push to be purely horizontal, but it makes the analysis easier.

A. Impulse

$\vec{J} = \vec{F}\Delta t = (9.10\,\text{N})(0.5\,\text{s}) = 4.55\,\text{N}\cdot\text{s}$, in the horizontal direction.

B. Final momentum

By the impulse-momentum theorem, the change in momentum is equal to the impulse applied, making it $4.55\,\mathrm{kg\cdot m/s}$ in the horizontal direction.

5. Alpha Centauri AB

We want to find the distance of the center of mass of the system from star A, so if we put the origin at star A, we'll get the distance directly from the formula.

$$x_{\mathrm{cm}} = \frac{x_A m_A + x_B m_B}{m_A + m_B} = \frac{0 + (16\,\mathrm{AU})(0.9 M_\odot)}{1.1 M_\odot + 0.9 M_\odot} = 7.2\,\mathrm{AU}$$

6. Rigid pendulum

This scenario was used to test many standards.

A. Gravitational potential energy in terms of y

$U_g = mgy$. We know m and g, so we also could express this as $U_g = (1.96\,\mathrm{N})y$.

B. Gravitational potential energy in terms of θ

$U_g = mgL(1 - \cos\theta) = (0.882\,\mathrm{J})(1 - \cos\theta)$.

C. Speed at $\theta = -20°$ after release from rest at $\theta = 50°$

This is a conservation of mechanical energy problem. The forces acting on the pendulum are gravity, which is conservative, and the tension or compression of the rod, which is always perpendicular to the path of the point mass. Since it does zero work, it also is conservative.

The total mechanical energy at 50° equals the total mechanical energy at −20°.

$$\begin{aligned}
K_0 + U_0 &= K_1 + U_1 \\
0 + mgL(1 - \cos\theta_0) &= 1/2\, m v_1^2 + mgL(1 - \cos\theta_1) \\
2gL(1 - \cos\theta_0) &= v_1^2 + 2gL(1 - \cos\theta_1) \\
v_1^2 &= 2gL(1 - \cos\theta_0 - 1 + \cos\theta_1) \\
v_1^2 &= 2gL(\cos\theta_1 - \cos\theta_0) \\
v_1^2 &= (8.82\,\mathrm{m^2/s^2})\{\cos(-20°) - \cos(50°)\} \\
v_1^2 &= (8.82\,\mathrm{m^2/s^2})(0.297) = 2.618\,\mathrm{m^2/s^2} \\
v &= 1.62\,\mathrm{m/s}
\end{aligned}$$

D. Forces on the pendulum

These have already been identified as the weight of the point mass and the tension or compression of the rod, both conservative.

Questions E–G reference the case in which the total mechanical energy is 1.2 joules and the pendulum is momentarily at an angle of $\pi/3$. That total energy is less than the maximum potential energy, so the pendulum cannot swing over the top. It can swing up to where the potential energy is 1.2 joules. According to the graph, that is about $\pm 2\pi/3$, or ±120°. According to the formula, the limiting angles are $\arccos(-0.36) = \pm 1.94$ radians $= \pm 111°$.

E. Potential energy of the pendulum

At an angle of $\pi/3$, the graph indicates that U_g is about 0.5 joules. The formula tells us it's $(0.882\,\mathrm{J})(1 - \cos\pi/3) = 0.441\,\mathrm{J}$, so close enough.

F. Kinetic energy of the point mass

With the total mechanical energy being 1.2 joules and the potential energy 0.441 joules, the kinetic energy must be the difference, 0.759 joules.

G. Motion of the pendulum

The pendulum will oscillate between the nearest angles where the potential energy equals the total mechanical energy, because there it won't have any kinetic energy to carry it any farther. Those angles were identified earlier as $\pm 1.94\,\text{radians} = \pm 111°$. The pendulum will momentarily stop and reverse direction at those angles, and move the fastest at $0°$.

H. Total mechanical energy 2.5 joules

That energy is greater than the highest potential energy anywhere, so the pendulum can rotate through any angle. It never turns around; it just keeps spinning forever without any non-conservative forces. It will be slowest at the top of the circle, which is at angles of $(2n+1)\pi, n = ..., -2, -1, 0, 1, 2, ...$ It will be fastest when it hangs straight down, which is at angles of $2n\pi$.

7. Momentum

Momentum is a vector.

8. Collision on 9th Street

The cars are moving the same direction, so for ease of notation we'll make that direction positive. They lock bumpers in the collision, meaning that they travel together. Thus, it is a totally inelastic collision, and their final velocities are the same. The common final velocity is given by

$$v_f = \frac{m_1 v_{1i} + m_2 v_{2i}}{m_1 + m_2}.$$

A. Initial momentum of the 1500-kg car

$$p_{1i} = m_1 v_{1i} = (1500\,\text{kg})(30\,\text{mi/h}) = 45,000\,\text{kg}\cdot\text{mi/h} = 20,115\,\text{kg}\cdot\text{m/s}$$

We already specified that the velocity is in the $+x$, or $\hat{\imath}$, dirtection. The momentum is in the same direction.

B. Initial momentum of the 1750-kg car

$$p_{1i} = m_2 v_{2i} = (1750\,\text{kg})(20\,\text{mi/h}) = 35,000\,\text{kg}\cdot\text{mi/h} = 15,645\,\text{kg}\cdot\text{m/s}$$

Also in the $\hat{\imath}$ direction, as this is a rear-end collision.

C. Final momentum of the 1500-kg car

To find its final momentum, we need to know its final velocity, which is given by the formula above.

$$\begin{aligned} v_f &= \frac{m_1 v_{1i} + m_2 v_{2i}}{m_1 + m_2} = \frac{45,000\,\text{kg}\cdot\text{mi/h} + 35,000\,\text{kg}\cdot\text{mi/h}}{3250\,\text{kg}} \\ &= \frac{80,000}{3250}\,\text{mi/h} = 24.61\,\text{mi/h} \\ &= 11.00\,\text{m/s} \end{aligned}$$

The momentum, then, is

$$m_1 v_{1f} = 36,923\,\text{kg}\cdot\text{mi/h} = 16,503\,\text{kg}\cdot\text{m/s}.$$

To an appropriate number of significant figures (3), that's $36,900\,\text{kg}\cdot\text{mi/h}$ or $16,500\,\text{kg}\cdot\text{m/s}$.

D. Final momentum of the 1750-kg car

e use the same final velocity as the 1500-kg car to obtain $43,077\,\text{kg}\cdot\text{mi/h} = 19,253\,\text{kg}\cdot\text{m/s}$. To three significant figures, that is $43,100\,\text{kg}\cdot\text{mi/h}$ or $19,300\,\text{kg}\cdot\text{m/s}$.

E. Type of collision

It has to be a totally inelastic collision.

F. Total kinetic energy

Total kinetic energy decreases in the collision.

9. Elastic neutron-alpha particle collision

We are told that the particles recoil along the line of approach. The outcome of such an elastic collision is given by

$$\begin{aligned} v_{1f} &= v_{1i}\frac{m_1 - m_2}{m_1 + m_2} + v_2 i\frac{2m_2}{m_1 + m_2} \\ v_{2f} &= v_{2i}\frac{m_2 - m_1}{m_1 + m_2} + v_1 i\frac{2m_1}{m_1 + m_2} \end{aligned}$$

A. Final velocity of neutron

The formula yields $-597\,\text{m/s}$.

B. Final velocity of alpha particle

The formula yields $+403\,\text{m/s}$.

We observe that the velocity difference after the collision is indeed $1000\,\text{m/s}$, the same as before the collision. This is required for an elastic collision.

10. Wheels on the bus

The question explicitly specifies an initial angular velocity $\omega_0 = 12.0\,\text{rad/s}$, final angular velocity $\omega = 22.0\,\text{rad/s}$, duration $\Delta t = 10.0\,\text{s}$, a radius $r = 0.54\,\text{m}$, and that the acceleration is constant. It implies but does not explicitly specify that the wheels roll without slipping.

A. Angular displacement

To find the angular displacement from the information given, the most direct equation to use is

$$\Delta\theta = 1/2\,(\omega_0 + \omega)\Delta t = 17(\,\text{m/s})(10.0\,\text{s}) = 170\,\text{radians}$$

B. Linear displacement

Because the wheels roll without slipping, $\Delta x = r\Delta\theta = 91.8\,\text{meters}$.