Name: ______________________________

AP Physics C: Mechanics
Summer Packet ‘24

MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

$\mathbf{J} = \int \mathbf{F}\,dt = \Delta\mathbf{p}$

$\mathbf{p} = m\mathbf{v}$

$F_{fric} \le \mu N$

$W = \int \mathbf{F} \cdot d\mathbf{r}$

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

$P = \frac{dW}{dt}$

$P = \mathbf{F} \cdot \mathbf{v}$

$\Delta U_g = mgh$

$a_c = \frac{v^2}{r} = \omega^2 r$

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$

$I = \int r^2 dm = \sum mr^2$

$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$

$v = r\omega$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$

$K = \frac{1}{2}I\omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$x = x_{max}\cos(\omega t + \phi)$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$

$U_G = -\frac{Gm_1m_2}{r}$

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$

$E = -\frac{dV}{dr}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$C = \frac{Q}{V}$

$C = \frac{\kappa\epsilon_0 A}{d}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$I = \frac{dQ}{dt}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$R = \frac{\rho\ell}{A}$

$\mathbf{E} = \rho\mathbf{J}$

$I = Nev_d A$

$V = IR$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$P = IV$

$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux
κ = dielectric constant

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$

$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$

$\mathbf{F} = \int I\,d\boldsymbol{\ell} \times \mathbf{B}$

$B_s = \mu_0 nI$

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

$\mathcal{E} = \oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2}LI^2$

- You only need the **Mechanics** side of equations sheet (left-hand side) for our class. 🙂

The purpose of this summer packet is to provide an introduction to every topic within the AP Physics C: Mechanics curriculum. The best way to tackle the problem solving in this packet is to utilize the following resources:

- My slides
- Physics for Scientists & Engineers: A Strategic Approach with Modern Physics by Randall Knight (any edition)
- Physics: Principles with Applications by Douglas Giancoli (any edition)
- Online resources including YouTube, Khan Academy, etc.

Directions: Please complete the kinematics, projectile motion, and dynamics sections of this packet. These are required (expect an assessment our first week on this content). The rest of the packet is optional, but recommended!

You are more than welcome (in fact, encouraged!) to collaborate on the entirety of this document. Please feel free to use your own notebook or any note-taking software (e.g. OneNote) to allow yourself plenty of space to interact with the content. Finally, don't make it all or nothing! If you try some of it, great. If you complete the whole thing, even better.

Feel free to use $g = 10\ m/s^2$ throughout this packet — note that answers may vary due to rounding and g as 9.8, 9.81. or $10\ m/s^2$. If your answer is within a tolerance of ±3%, you have the correct answer.

Kinematics:

1. A stone is thrown vertically upward with a speed of 15 m/s from the top of a cliff that is 65 m high.

   a. How much later does the stone reach the bottom of the cliff?

   b. How high did it go from the edge of the cliff to where it was thrown?

   c. What is the (magnitude of the) velocity of the stone just before it hits the ground?

   d. What total vertical distance did it travel?

   e. Sketch the graphs of position vs. time, x(t), velocity vs. time, v(t), and acceleration vs. time, a(t) for the **entirety** of the motion.

2. A Chevy El Camino whose velocity is +20 m/s passes a stationary motorcycle cop, who immediately begins chasing the car with a constant acceleration of $+2.4\ m/s^2$.

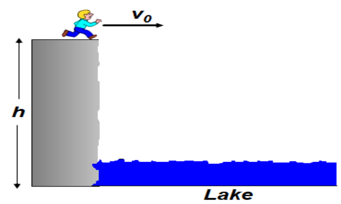
   a. How far will the motorcycle cop travel before catching the car?

   b. What will be the motorcyclist's velocity at that time?

   c. How does that compare to the car's velocity?

d. Draw the following graphs for the car: x(t), v(t), & a(t).

Projectile Motion:

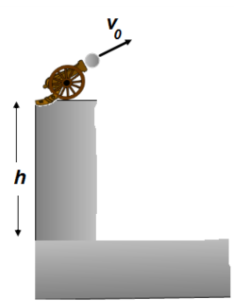


3. A boy dives off of a cliff with a running (purely) horizontal velocity of 8.6 m/s. The distance from the edge of the cliff to the surface of the lake below is 12 m.

a. How much time will it take the boy to fall from the edge of the cliff to the surface of water?

b. How far (in the horizontal / x-direction) from the cliff will he strike the surface of water?

c. What is his landing velocity (magnitude)?



4. A pirate's cannon ball is fired from his cannon located at the edge of 34-m–tall cliff. The initial velocity of the cannon ball has a magnitude of 540 m/s and an angle of 42˚ above the horizontal (0.

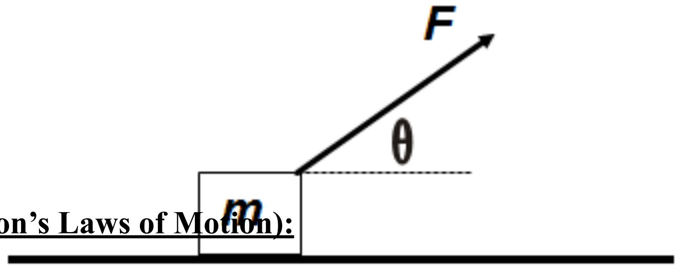
a. How much time is required for the cannon ball to reach the ground?

b. How far from the cliff will the cannon ball strike the ground?

c. What is the maximum height reached by the cannon ball?

d. What is the landing velocity of the cannon ball (magnitude and direction)?

Dynamics (AKA Newton's Laws of Motion):



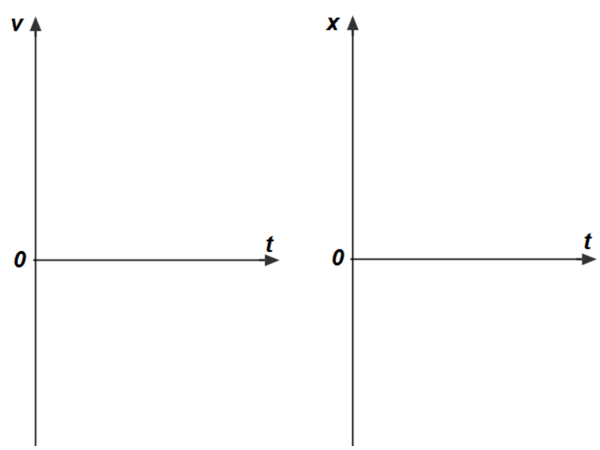
5. A block of mass m is pulled along a rough horizontal surface by a force F that is applied at an angle θ above the horizontal. The block moves at a constant horizontal acceleration, a. Express all results (answers) in terms of m, θ, F, a, and fundamental constants (like g, for example).

    a. Draw and label a free-body diagram showing all the forces acting on the block.

    b. Write an expression for the normal force applied by the surface to the block.

    c. Determine the coefficient of kinetic friction between the block and the surface.

    d. Sketch two graphs on the axes below: velocity and displacement as functions of time, assuming the block started from rest at x = 0 and t = 0.



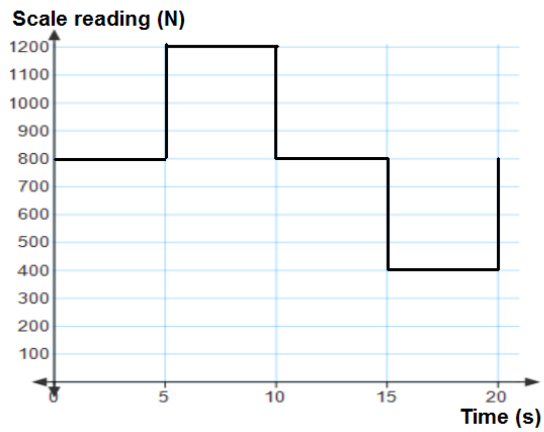
6. An 80.0 kg passenger stands on a scale in an elevator (no one knows why there's a scale in the elevator). The scale's reading for the first 20.0 s are presented in the graph below. Use $g = 10\ m/s^2$ in the following calculations.

   a. Calculate the acceleration of the elevator for the following time intervals: 0-5 s; 5-10 s; 10-15 s; 15-20 s.

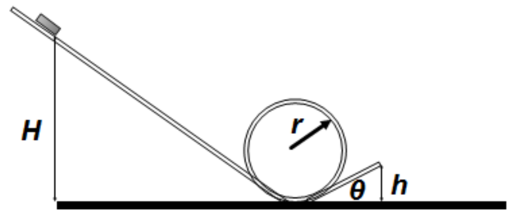
   b. Calculate the velocity (magnitude) of the elevator at the end of the following time intervals: 0-5 s; 5-10 s; 10-15 s; 15-20 s.

   c. Calculate the displacement of the elevator from the starting point to the end of the following time intervals: 0-5 s; 5-10 s; 10-15 s; 15-20 s.

   d. Draw the following graphs: a(t), v(t), x(t).



Work & Energy:



7. A small block of mass m = 0.5 kg is released from rest at the top of an inclined ramp at H = 2 m above ground level. The ramp has a circular section of radius r = 0.5 m and another small inclined section at the end with a height h = 0.3 m at $\theta = 37^\circ$above the horizontal, as shown above. The friction force is negligible as the block slides on all the surfaces.

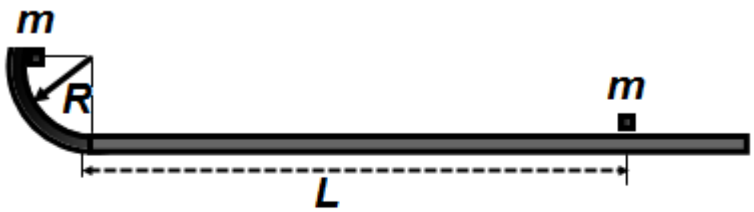
    a. Find the speed of the block at the top of the circular section of the ramp.

    b. Find the normal force on the block when it is at the top of the circular section of the ramp.

    c. Find the speed of the block at the bottom of the circular section of the ramp.

    d. Find the normal force on the block when it is at the bottom of the circular section of the ramp.

    e. When the block leaves the ramp it flies as a projectile. Find the maximum horizontal distance and the maximum height reached by the block.



8. A box with a mass m = 0.2 kg is released from rest at the top of a curved section of a track (displayed above) that is one quarter of a circle with a radius R = 1.5 m. When the box reaches the bottom of the curved track it slides on a rough horizontal section of the track. The coefficient of kinetic friction between the box and the horizontal section is 0.2. There is no friction on the curved section of the track.

   a. Find the velocity of the box at the bottom of the curved section of the track.

   b. Find the stopping distance of the box on the horizontal section of the track.

   c. If friction is present on the curved section of the track, how would it change the answer to part b?

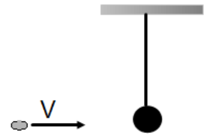
Momentum:

9. A bullet of mass m = 10 g moves at a velocity v_0 = 500 m/s and collides with a stationary block of mass M = 1.2 kg. The bullet passes through the block and emerges with a speed v = 100 m/s. After the collision the block moves a distance d = 90 cm along the surface until it comes to rest.

   a. Find the velocity of the block after the collision.

   b. Find the change in kinetic energy of the bullet-block system.

   c. Find the coefficient of kinetic friction between the block and the surface.



10. A 20.0 g piece of clay moves with a constant speed of 15.0 m/s. The piece of clay collides and sticks to a massive (as in, has mass) ball of mass 0.900 kg suspended at the end of a string.

    a. Calculate the momentum of the piece of clay before the collision.

    b. Calculate the kinetic energy of the piece of clay before the collision.

    c. What is the momentum of two objects after the collision?

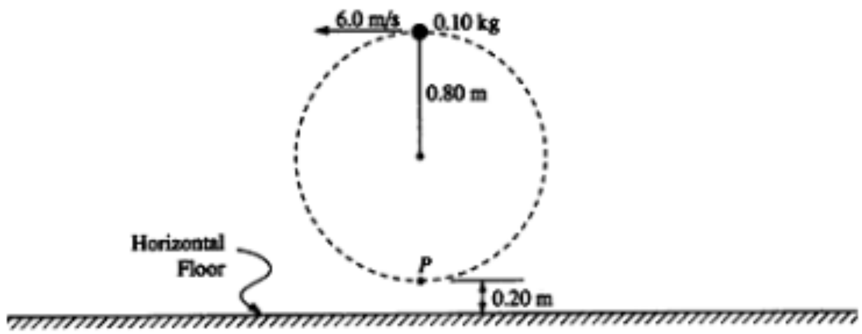
    d. Calculate the velocity of the combination of two objects after the collision.

    e. Calculate the kinetic energy of the combination of two objects after the collision.

    f. Calculate the change in kinetic energy during the collision.

    g. Calculate the maximum vertical height of the "clay-ball system" after the collision.

Uniform Circular Motion:



11. A 0.10-kilogram solid rubber ball is attached to the end of an 0.80-meter length of light thread. The ball is swung in a vertical circle, as shown in the diagram above. Point P, the lowest point of the circle, is 0.20 meter above the floor. The speed of the ball at the top of the circle is 6.0 meters per second, and the total energy of the ball is kept constant.

    a. Determine the total energy of the ball, using the floor as the zero point for gravitational potential energy.

    b. Determine the speed of the ball at point P, the lowest point of the circle.

    c. Determine the tension in the thread at
        i. the top of the circle;
        ii. the bottom of the circle.

    Now take the case where the ball only reaches the top of the circle once before the thread breaks when the ball is at the lowest point of the circle.

    d. Determine the horizontal distance that the ball travels before hitting the floor.

Universal Gravitation:

12. A 2.10-kg brass ball is transported to the Moon via the Artemis III mission. (The radius of the Moon is 1.74×10^6 m and its mass is 7.35×10^{22} kg.)

    (a) Calculate the acceleration due to gravity on the Moon.

    (b) Determine the mass of the brass ball on Earth and on the Moon.

    (c) Determine the weight of the brass ball on Earth.

    (d) Determine the weight of the brass ball on Moon.

Content Outline for AP Physics C

A more detailed topic outline is contained in the "Learning Objectives for AP Physics C," which follow this outline.

Content Area	*Percentage Goals for Exams*
AP Physics C: Mechanics	100%
A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration) 1. Motion in one dimension 2. Motion in two dimensions, including projectile motion	18%
B. Newton's laws of motion 1. Static equilibrium (first law) 2. Dynamics of a single particle (second law) 3. Systems of two or more objects (third law)	20%
C. Work, energy, power 1. Work and work–energy theorem 2. Forces and potential energy 3. Conservation of energy 4. Power	14%
D. Systems of particles, linear momentum 1. Center of mass 2. Impulse and momentum 3. Conservation of linear momentum, collisions	12%
E. Circular motion and rotation 1. Uniform circular motion 2. Torque and rotational statics 3. Rotational kinematics and dynamics 4. Angular momentum and its conservation	18%
F. Oscillations and gravitation 1. Simple harmonic motion (dynamics and energy relationships) 2. Mass on a spring 3. Pendulum and other oscillations 4. Newton's law of gravity 5. Orbits of planets and satellites a. Circular b. General	18%

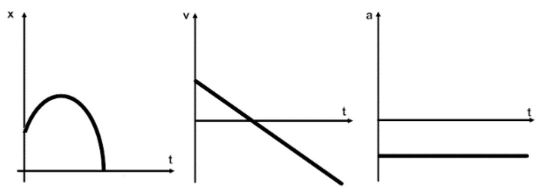
Answers (Solutions will be provided in class):

1.
   a. t = 5.4 s

   b. h = 11.25 m from the edge of the cliff

   c. v = -39 m/s

   d. x = 87.5 m

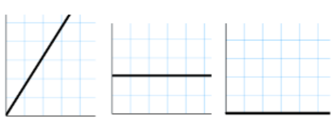
   e. 

2.

   a. 334.67 m

   b. +40.08 m/s

   c. Twice the velocity / it has doubled / 100% increase

   d. 

3.

   A. 1.55 s

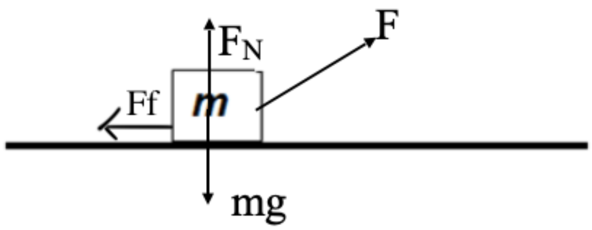
   B. 13.32 m

   C. 17.73 m/s

4.
   A. 72.36 s
   B. 29,037 m
   C. 6493 m
   D. 540.63 m/s @ -42.07˚, or @ 42.07˚ below the horizontal

. 5.

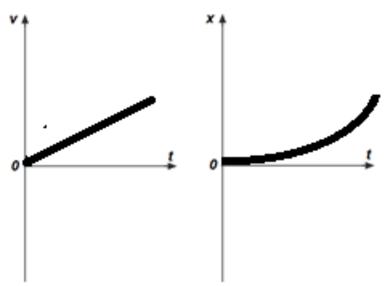
A.



B. $F_N = mg - F\sin\theta$

C. $\mu_k = \dfrac{F\cos\theta - ma}{mg - F\sin\theta}$ or $\mu_k = \dfrac{F\cos\theta}{mg - F\sin\theta}$

D.



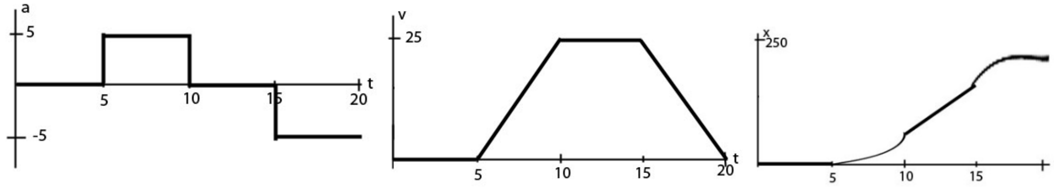
6.

a) $a_{(0\text{-}5s)} = 0\ m/s^2$, $a_{(5\text{-}10s)} = 5\ m/s^2$, $a_{(10\text{-}15s)} = 0\ m/s^2$, $a_{(15\text{-}20s)} = -5\ m/s^2$

b) $v_{(0\text{-}5s)} = 0$ m/s, $v_{(5\text{-}10s)} = 25$ m/s, $v_{(10\text{-}15s)} = 25$ m/s, $v_{(15\text{-}20s)} = 0$ m/s

c) $x_{(0\text{-}5s)} = 0$ m, $x_{(5\text{-}10s)} = 62.5$ m, $x_{(10\text{-}15s)} = 187.5$ m, $x_{(15\text{-}20s)} = 250$ m

d)



7.

a. 4.47 m/s
b. 14.98 N
c. 6.32 m/s
d. 44.94 N
e. Height = 1.02 m, Horizontal Distance = 4.29 m

8.

a. 5.48 m/s
b. 7.51 m
c. It would lower the answer to b; in other words, if friction were present in curved section, it would lower the initial velocity, so the object would travel a shorter distance before stopping

9. a. v = 3.33 m/s

b. ΔKE = -1193.35 J; this means that kinetic energy was lost, which makes sense

c. μ= 0.61

10. a. 0.3 kg m/s
b. 2.25 J
c. 0.3 kg m/s
d. 0.33 m/s
e. 0.05 J
f. -2.2 J
g. 0.0054 m

11. a. 3.6 J
b. 8.25 m/s
c. i. 3.5 N
ii. 9.5 N
d. 1.65 m

12. a. 1.62 m/s^2
b. 2.10 kg
c. 21 N
d. 3.4 N