Physics 105

Physics for the Life Sciences I

Mechanics, Thermodynamics, and Oscillators

Course Manual

PHYS 105
Sections: 03A + 04A
Even Days: 11:00 + 1:00

Text:
College Physics, 9th Edition
with Enhanced WebAssign
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Fall 2012
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Home work will be assigned via `WebAssign.net`. Generally homework is due before midnight on the following lecture day. Late homework will be assessed a 15% penalty. While the web promises global connections, it often promotes isolation. Consider avoiding web-induced isolation by forming a problem solving group. (Everybody's problems will be slightly different, but the algebra and thought required to solve the problems will be the same.) Or just work the homework with classmates in our “Physics Library” PEngel 104; I'll then be near by when you have questions. Note that assigned homework should just be the start to developing your problem solving skills: work extra odd problems and check the answer in the back of the textbook!

To use WebAssign for homework you will need the access code you purchased with your textbook to self-register for your course section.

1. Go to http://www.webassign.net/login.html
2. Click on the “I have a class key” button below the “Login” button
3. Enter the class key corresponding to your class section listed below:

11:00	Section 03A	csbsju 7919 7051
1:00	Section 04A	csbsju 8613 6133

Topic 1 – Fundamentals
Cycle 1, Day 2

Reading: "To The Student" & Chapter 1

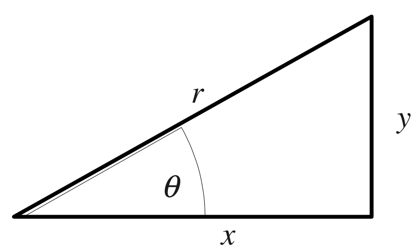
Objectives:

1. Be able to give standard units of distance, mass, and time in the MKS (SI) system.
2. Be able to use the following prefixes: giga, mega, kilo, centi, milli, micro (μ), nano. Understand scientific notation and, in particular, the **E** notation used by computers and WebAssign.
3. Be able to perform **dimensional analysis**.
4. Be able to correctly apply uncertainties in measurements and significant figures (**sigfigs**) to calculations.
5. Be able to **convert units** (e.g., miles per hour to meters per second).
6. Be able to make order of magnitude estimations.
7. Be able to use fundamental algebra and **trigonometry** (sine, cosine, tangent and Pythagorean theorem) and perform conversions between rectangular and polar coordinates.

Equations to Know from Memory:

Pythagorean Theorem: $r^2 = x^2 + y^2$

Sine of angle: $\sin\theta = \frac{y}{r}$



Cosine of angle: $\cos\theta = \frac{x}{r}$

Tangent of angle: $\tan\theta = \frac{y}{x}$

Topic 2 – One-Dimensional Kinematics

Cycle 1, Days 46

Reading: Chapter 2

Objectives:

1. Be able to define mathematically and in words and graphs: displacement, speed, average velocity, instantaneous velocity, average acceleration, and instantaneous acceleration.
2. Be able to graph motion and **interpret motion graphs**.
3. Be able to solve problems involving **uniformly accelerated motion** using the equations of motion.

Equations to Know from Memory:

Displacement: $\Delta x \equiv x_f - x_i$

Average Velocity: $\bar{v} \equiv \frac{\Delta x}{\Delta t} \equiv \frac{x_f - x_i}{t_f - t_i}$; $\bar{v} = \frac{v_0 + v}{2}$ (for constant a)

Instantaneous Velocity: $v \equiv \lim_{\Delta t \to 0} \bar{v} \equiv \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$

Average Acceleration: $\bar{a} \equiv \frac{\Delta v}{\Delta t} \equiv \frac{v_f - v_i}{t_f - t_i}$

Instantaneous Acceleration: $a \equiv \lim_{\Delta t \to 0} \bar{a} \equiv \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t}$

Equations for Uniformly Accelerated Motion
(for Free Fall replace x with y and a with $-g$):

$$v = v_0 + at \qquad \Delta x = v_0 t + \frac{1}{2} a t^2 \qquad v^2 = v_0^2 + 2 a \Delta x$$

Physical Constants to Know:

Acceleration due to gravity: $g = 9.80 \text{ m/s}^2 = 32 \text{ ft/s}^2$

Topic 3 – Vectors and Two-Dimensional Kinematics

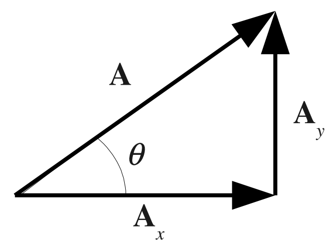
Cycle 2, Days 24

Reading: Chapter 3

Objectives:

1. Be able to state the definitions of vector and scalar quantities (and give examples of each).
2. Be able to multiply and divide a vector by a scalar.
3. Apply **trigonometry** to find rectangular components of a vector.
4. Be able to add and subtract vectors graphically and with the use of rectangular components.
5. Be able to define displacement, velocity, and acceleration vectors.
6. Be able to solve **projectile motion** problems.
7. Be able to calculate relative velocities.

Equations to Know from Memory:



Trigonometric Expressions for Vectors:

$A^2 = A_x^2 + A_y^2 \quad A_x = A\cos\theta \quad A_y = A\sin\theta \quad \tan\theta = \frac{A_y}{A_x}$

$\vec{\mathbf{A}} = \vec{\mathbf{A}}_x + \vec{\mathbf{A}}_y \quad \left|\vec{\mathbf{A}}\right| \equiv A = \sqrt{A_x^2 + A_y^2}$

Displacement Vector: $\Delta\vec{\mathbf{r}} = \vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i$

Velocity Vector: $\vec{\mathbf{v}}_{av} \equiv \frac{\Delta\vec{\mathbf{r}}}{\Delta t} \quad \vec{\mathbf{v}} \equiv \lim_{\Delta t \to 0} \frac{\Delta\vec{\mathbf{r}}}{\Delta t}$

Acceleration Vector: $\vec{\mathbf{a}}_{av} \equiv \frac{\Delta\vec{\mathbf{v}}}{\Delta t} \quad \vec{\mathbf{a}} \equiv \lim_{\Delta t \to 0} \frac{\Delta\vec{\mathbf{v}}}{\Delta t}$

Equations of Motion:

$v_x = v_{0x} + a_x t \quad \Delta x = v_{0x}t + \frac{1}{2}a_x t^2 \quad v_x^2 = v_{0x}^2 + 2a_x\Delta x \quad v = \sqrt{v_x^2 + v_y^2}$

$v_y = v_{0y} + a_y t \quad \Delta y = v_{0y}t + \frac{1}{2}a_y t^2 \quad v_y^2 = v_{0y}^2 + 2a_y\Delta y \quad \theta = \tan^{-1}\left(\frac{v_y}{v_x}\right)$

For Projectile Motion: $a_x = 0 \quad v_x = v_{0x} = v_0\cos\theta \quad a_y = -g \quad v_{0y} = v_0\sin\theta$

Relative Velocity: $\vec{\mathbf{v}}_{\mathrm{AB}} = \vec{\mathbf{v}}_{\mathrm{AE}} - \vec{\mathbf{v}}_{\mathrm{BE}}$

Topic 4 – Newton's Laws

Cycle 2, Day 6; Cycle 3, Days 24

Reading: Chapter 4

Objectives:

1. Be able to state the difference between mass and **weight**.
2. Be able to state Newton's three laws and explain their implications to physical phenomena. Be able to explain in words the meaning of notations like: $\sum \vec{\mathbf{F}}$ and $\sum m_i x_i$.
3. Be able to define the Newton.
4. Be able to define in words and mathematically Newton's law of universal gravitation.
5. Be able to distinguish between inertial and non-inertial reference frames.
6. Be able to describe the difference between static and kinetic **friction**.
7. Be able to work with **tension**, compression, and **normal** forces.
8. Be able to **apply Newton's laws** to problems in one and two dimensions.
9. Be able to make **free body diagrams**

Equations to Know from Memory:

Newton's First Law: $\vec{\mathbf{v}} = \text{constant}$ unless $\sum \vec{\mathbf{F}} \neq 0$

Newton's Second Law: $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$

Newton's Third Law: $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$

Newton's Universal Law of Gravitation: $F_g = G\dfrac{m_1 m_2}{r^2}$

Weight: $w = mg$ $\quad g = \dfrac{F_g}{m} = G\dfrac{M_E}{R_E^2} = 9.80\ \text{m/s}^2$

Conditions for Equilibrium: $\sum \vec{\mathbf{F}} = 0$ $\quad \vec{\mathbf{v}} = \text{constant}$

Frictional Forces: $f_s \leq \mu_s n$ (static) $\quad f_k = \mu_k n$ (kinetic)

Topic 5 – Work, Energy, and Power
Cycle 4, Days 46

Reading: Chapter 5

Objectives:

1. Be able to define in words and mathematically **work**, **kinetic energy**, and **potential energy** and make calculations of each.
2. Be able to describe the difference between conservative and nonconservative forces.
3. Be able to mathematically apply the **Work-Energy Theorem**.
4. Be able to state and apply the principle of **conservation of energy**.
5. Be able to **graphically** find the work done by a varying force.
6. Be able to solve problems involving **springs**.
7. Be able to define power, define the unit of power, and calculate power.

Equations to Know from Memory:

Work: $W \equiv (F \cos\theta)\Delta x$ Hooke's Law: $F = -kx$

Kinetic Energy: $KE \equiv \frac{1}{2}mv^2$ Gravitational Potential Energy: $PE_g \equiv mgy$

Spring Potential Energy: $PE_s \equiv \frac{1}{2}kx^2$

Work-Energy Theorem: $W_{nc} + W_c = \Delta KE$ $W_{nc} = \Delta KE + \Delta PE_g + \Delta PE_s = E_f - E_i$

Power: $\bar{P} = \dfrac{W}{\Delta t} = F\bar{v}$

Topic 6 – Momentum and Collisions

Cycle 5, Days 24

Reading: Chapter 6

Objectives:

1. Be able to define and calculate **momentum** and impulse.
2. Be able to apply Newton's laws to impulse and change of momentum problems.
3. Be able to state and apply the law of **conservation of linear momentum**.
4. Be able work out **elastic and inelastic collision problems**.
5. Be able to work out glancing collision problems.
6. Be able to describe how rocket propulsion works in terms of momentum.

Equations to Know from Memory:

Impulse: $\vec{\mathbf{I}} \equiv \vec{\mathbf{F}} \Delta t$ (more generally: area under force vs time curve)

Momentum: $\vec{\mathbf{p}} \equiv m \vec{\mathbf{v}}$

Impulse-Momentum Theorem: $\vec{\mathbf{I}} = \Delta \vec{\mathbf{p}} = m \vec{\mathbf{v}}_f - m \vec{\mathbf{v}}_i$

Conservation of Momentum: $\sum \vec{p}_i = \sum \vec{p}_f$

e.g., 2 objects $m_1 \vec{\mathbf{v}}_{1i} + m_2 \vec{\mathbf{v}}_{2i} = m_1 \vec{\mathbf{v}}_{1f} + m_2 \vec{\mathbf{v}}_{2f}$

Applied to 1-D Perfectly Inelastic Collisions:

$m_1 v_{1i} + m_2 v_{2i} = (m_1 + m_2) v_f$

Applied to 1-D Elastic Collisions:

$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$ $\quad \frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2$

$v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$

Topic 7 – Circular Motion and Gravitation

Cycle 5 Day 6, Cycle 6 Day 2

Reading: Chapter 7

Objectives:

1. Be able to relate **angular displacement** to arc length, **angular velocity** to tangential velocity, and **angular acceleration** to tangential acceleration. Be able to appropriately use and convert angular units of degrees and radians.
2. Be able to use the **equations of motion** for constant angular acceleration.
3. Be able to relate **centripetal acceleration** to angular velocity and identify **centripetal forces**.
4. Be able to state Newton's law of universal gravitation and apply it to problems.
5. Be able to describe the difference between bound and unbound systems in terms of their mechanical energy.
6. Be able to state and apply Kepler's Laws.

Equations to Know from Memory:

Arc Length: $s=r\theta$

Angular Velocity: $\omega\equiv\frac{\Delta\theta}{\Delta t}=2\pi f$ Tangential Velocity: $v_t=r\omega$

Angular Acceleration: $\alpha\equiv\frac{\Delta\omega}{\Delta t}$ Tangential Acceleration: $a_t=r\alpha$

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

Equations of Rotational Motion for constant α :

$\omega=\omega_i+\alpha t$ $\Delta\theta=\omega_i t+\frac{1}{2}\alpha t^2$ $\omega^2=\omega_i^2+2\alpha\Delta\theta$

Newton's Universal Law of Gravitation: $F=G\frac{m_1 m_2}{r^2}$

Gravitational Potential Energy: $PE_g=-G\frac{m_1 m_2}{r}$

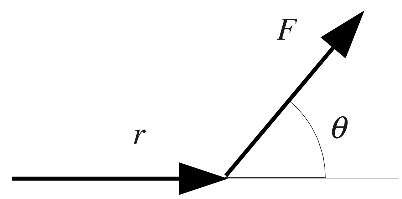
Topic 8 – Rotational Dynamics
Cycle 6, Days 46

Reading: Chapter 8

Objectives:

1. Be able to define **torque** and **moment of inertia**
2. Be able to work problems involving **static equilibrium**.
3. Be able to calculate the **center of gravity** of a distributed object.
4. Be able to state and use the relation between torque, angular acceleration and moment of inertia.
5. Be able to solve **problems** and draw **free body diagrams** in situations involving torque.
6. Be able to define **rotational kinetic energy** and **angular momentum**.
7. Be able to apply the **conservation of angular momentum** to problems.

Equations to Know from Memory:



Torque: $\tau = rF\sin\theta$

Moment of Inertia: $I = \sum mr^2$

Newton's Second Law for Rotation: $\sum \tau = I\alpha$

Rotational Kinetic Energy: $KE_r = \frac{1}{2} I \omega^2$

Work-Energy Theorem: $W_{nc} = \Delta KE_t + \Delta KE_r + \Delta PE$

Angular Momentum: $L \equiv I\omega$ $\qquad \sum \tau = \frac{\Delta L}{\Delta t}$

Conservation of Angular Momentum: $\sum \tau = 0 \Rightarrow I_i \omega_i = I_f \omega_f$

Topic 9 – Fluids
Cycle 7 Days 6; Cycle 8 Days 24

Reading: Chapter 9

Objectives:

1. Be able to describe the differences between solids, fluids, gases, and plasmas.
2. Be able to state the relationship between **stress** and **strain** and apply it to the **elasticities** of length, shape, and volume.
3. Be able to define **density** and **pressure** and determine **pressure change with depth** in a fluid.
4. Be able to state and apply Pascal's principle.
5. Be able to state and apply **Archimedes' principle**.
6. Be able to define the viscosity of a fluid in words.
7. Be able to distinguish between laminar and turbulent flow.
8. Be able to apply the **equation of continuity** for problems involving incompressible fluids.
9. Be able to explain Bernoulli's equation in terms of conservation of energy.
10. Be able to apply **Bernoulli's equation** to problems.
11. Be able to explain the contributions of surface tension and cohesive and adhesive forces to capillary action.
12. Be able to state the importance of the Reynolds number.
13. Be able to describe diffusion, osmosis, and Stoke's Law.

Equations to Know from Memory:

Deformation of solids: $\text{stress} = \text{elastic modulus} \times \text{strain}$

Density: $\rho = \frac{m}{V}$ Pressure: $P = \frac{F_{\perp}}{A}$

Variation of pressure with depth: $P = P_0 + \rho g \Delta h$

Archimedes' Principle: $B = \rho_{\text{fluid}} V_{\text{fluid}} g$

Continuity Equation: $A_1 v_1 = A_2 v_2$

Bernoulli's Equation: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

Physical Constants to Know:

Unit of Pressure, Pascal: $1\ \text{Pa} = 1\ \text{N/m}^2$ $\quad 1\ \text{atm} = 1.01 \times 10^5\ \text{Pa}$

Topic 10 – Thermal Physics

Cycle 8, Day 6; Cycle 9, Day 2

Reading: Chapter 10

Objectives:

1. Be able to state and apply the Zeroth Law of Thermodynamics.
2. Be able to describe the **Celsius**, Fahrenheit, and **Kelvin** temperature scales and convert from one to another.
3. Be able to explain and calculate thermal expansion.
4. Be able to state and apply the **Ideal Gas Law**.
5. Be able to state the assumptions of the kinetic theory of gases and apply the results of the theory.
6. Be able to state in words the meaning of notations like: $\sqrt{\langle \overline{v^2} \rangle} = v_{\text{rms}}$

Equations to Know from Memory:

Kelvin to Celsius: $T_C = T_K - 273.15$

Celsius to Fahrenheit: $T_F = \frac{9}{5} T_C + 32$

Thermal Expansion: $\Delta L = \alpha L_0 \Delta T$ $\quad \Delta A = \gamma A_0 \Delta T$ $\quad \Delta V = \beta V_0 \Delta T$

Ideal Gas Law: $PV = nRT$

Kinetic Theory: $P = \frac{2}{3}\left(\frac{N}{V}\right)\left(\frac{1}{2} m \overline{v^2}\right)$ $\quad \left(\frac{1}{2} m \overline{v^2}\right) = \frac{3}{2} k_B T$ $\quad U = \frac{3}{2} nRT$

$$v_{\text{rms}} = \sqrt{\frac{3 k_B T}{m}} = \sqrt{\frac{3RT}{M}}$$

Physical Constants to Know:

Avogadro's Number: $N_A = 6.02 \times 10^{23}$ particles/mol

Boltzmann's Constant: $k_b = 1.38 \times 10^{-23}$ J/K

Universal Gas Constant: $R \equiv N_A k_B = 8.314$ J/(K·mole)

Topic 11 – Heat and Energy Transfer
Cycle 9, Day 46

Reading: Chapter 11

Objectives:

1. Be able to state the difference between internal energy, temperature, and heat.
2. Be able to use and define **specific heats** and **latent heats**.
3. Be able to work simple heat transfer and **calorimetry problems**.
4. Be able to work heat transfer and calorimetry problems involving **phase changes**.
5. Be able to describe the differences between energy transfer by conduction, convection, and radiation.
6. Be able to state the significance of the emissivity, *e*, of a material and its range of values.
7. Be able to apply Stefan's Law to radiative heat transfer.
8. Be able to explain the greenhouse (atmospheric) effect in terms of Stefan's Law.

Equations to Know from Memory:

Specific Heat: $c \equiv \frac{Q}{m \Delta T}$

Phase Changes: $Q = \pm m L$

Thermal Conduction: $\mathcal{P} = kA \frac{(T_h - T_c)}{L}$ R-factor: $R = \frac{L}{k}$

Stefan's Law: $\mathcal{P} = \sigma A e T^4$

Physical Constants to Know:

$1 \text{ cal} \equiv 4.186 \text{ J}$

Note: 1 food calorie is equal to 1000 calories. $1 \text{ Cal} = 1 \text{ kcal}$

Topic 12 – Thermodynamics
Cycle 10, Days 24

Reading: Chapter 12

Objectives:

1. Be able to calculate the **work done** on or by a gas.
2. Be able to state and apply the First Law of Thermodynamics.
3. Be able to describe and graph **isobaric, adiabatic, isovolumetric,** and **isothermal** processes and calculate changes in thermodynamic quantities for these processes.
4. Be able to define and graph a **Carnot cycle**.
5. Be able to state the Second Law of Thermodynamics in 2 ways.
6. Be able to distinguish between reversible and irreversible processes.
7. Be able to discuss the operation of **heat engines** and **heat pumps** and calculate work done, efficiencies, and coefficients of performance assuming a Carnot cycle.
8. Be able to define entropy and calculate changes in entropy for systems.

Equations to Know from Memory:

Work done on a gas (constant P): $W = -P\,\Delta V$

First Law of Thermodynamics: $\Delta U = Q + W$

Isobaric Process: $Q = n C_p \,\Delta T$

Adiabatic Process: $Q = 0$ $\quad PV^{\gamma} = \text{constant}$ $\quad \gamma = \frac{C_p}{C_v}$

Isovolumetric Process: $W = 0$ $\quad Q = n C_v \,\Delta T$

Isothermal Process: $\Delta U = 0$ $\quad W = -Q$ $\quad W = nRT \ln\left(\frac{V_f}{V_i}\right)$

Heat Engines: $W_{\text{eng}} = |Q_h| - |Q_c|$ $\quad e \equiv \frac{W_{\text{eng}}}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$

Heat Pumps: $\text{COP (cooling mode)} = \frac{|Q_c|}{W}$ $\quad \text{COP (heating mode)} = \frac{|Q_h|}{W}$

Carnot Engines: $e_C = 1 - \frac{T_c}{T_h}$ $\quad$ Entropy: $\Delta S \equiv \frac{Q_r}{T}$

Enthalpy: $H = U + PV$ $\quad$ Gibbs Free Energy: $G = H - TS$

Physical Constants to Know:

Molar specific heat of monatomic gas at constant volume: $C_v \equiv \frac{3}{2} R$

Molar specific heat of monatomic gas at constant pressure: $C_p \equiv \frac{5}{2} R$

Topic 13 – Oscillations

Cycle 11, Days 46; Cycle 12, Days 24

Reading: Chapter 13

Objectives:

1. Understand the concepts of **amplitude, frequency, period,** and **angular frequency**. Appropriately use radians in trigonometric functions.
2. Be able to apply **conservation of energy** to simple harmonic oscillator problems.
3. Be able to work simple harmonic oscillator problems using **displacement, velocity, and acceleration**.
4. Be able to calculate the angular frequency for a simple harmonic oscillator.
5. Be able to describe the difference between transverse and longitudinal waves.
6. Understand the concepts of **amplitude, frequency, wave speed** and **wave length**.
7. Be able to describe **constructive and destructive interference** using the **superposition** principle.

Equations to Know from Memory:

Hooke's Law: $F_s = -kx$ Elastic Potential Energy: $PE_s \equiv \frac{1}{2} kx^2$

Simple Harmonic Motion:

Mass on a Spring: $v = \pm\sqrt{\frac{k}{m}(A^2 - x^2)}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $f = \frac{1}{T}$ $\omega = 2\pi f = \sqrt{\frac{k}{m}}$

Periodic Position: $x = A\cos(2\pi f t)$

Periodic Velocity: $v = -A\omega\sin(2\pi f t)$

Periodic Acceleration: $a = -A\omega^2\cos(2\pi f t)$

Simple Pendulum: $T = 2\pi\sqrt{\frac{L}{g}}$

Wave Speed: Generally $v = f\lambda$ on a string $v = \sqrt{\frac{F}{\mu}}$