Northwestern CT Community College
Course Syllabus

Course Title: CALCULUS-BASED PHYSICS I with Lab **Course #: PHY 221**

Course Description: 4 credits (3 class hours and 3 laboratory hours per week)

Physics 221 is designed primarily for physics, chemistry, mathematics and engineering majors. The use of cognitive and mathematical problem solving skills employed by scientists and engineers will also be a central focus of this course, students enrolled in Physics 221 will be expected to apply the knowledge of differential and integral calculus to solve physics problems. The subject areas include, but are not limited to; kinematics, dynamics, energy and momentum for the three primary forms of motion; translational, rotational and harmonic. The use of computers, analysis software, and electronics sensors will be an integral part of this course.

Prerequisite: PHY 221 - MAT* 254 with a grade of "C" or better.

Goals:
The goals of this course are to develop the students' abilities to understand, utilize, and apply a significant portion of the physics discipline. This course will provide students with an opportunity to demonstrate an understanding of the fundamental principles, concepts, and knowledge of the natural laws of classical (Newtonian) mechanics, assist students in applying these principles to the student's area of interest, and to develop analytical problem-solving skills important to scientists and engineers. We will utilize the derivative and integral in both conceptual definitions and problem solving.

Outcomes:
Upon successful completion of this course, each student must have demonstrated understanding and competency in each of the following topics and techniques (through in-class testing of each individual student independently and collaborative lab-work):

1. Relate the basic concepts of physics and the methods scientists use to explore natural phenomena, including observation, hypothesis development, measurement and data collection, experimentation, evaluation of evidence, and employment of mathematical analysis.
2. Demonstrate the numerical evaluation of algebraic results rapidly and accurately, using appropriate units for physical quantities, including scientific notation.
3. Analyze data to assess the relationships between variables with the objective of drawing logical conclusions from the analysis.
4. Describe simple physical systems by graphing system variables, and interpret graphs of system variables.
5. Represent and interpret quantitative information symbolically, graphically, numerically, verbally, and in written form:
    a. Interpret graphical representations of data illustrating such important concepts as distance vs. time and force vs. acceleration.
    b. Represent, in graphical form, results from computational or experimental methodologies

6. Devise, perform, and analyze properly controlled experiments to test hypotheses regarding basic physics principles.
7. Describe Newton's laws of motion, state physical examples of each law, apply them to simple mechanical systems and demonstrate them through experimentation.
   Explain the concept of force
   a. Define the displacement and average velocity of a particle in motion.
   b. Define the instantaneous velocity and understand how this quantity differs from average velocity.
   c. Define average acceleration and instantaneous acceleration.
   d. Construct position versus time and velocity versus time graphs for a particle in motion along a straight line. From these graphs, determine both average and instantaneous values of velocity and acceleration.
   e. Obtain the instantaneous velocity and instantaneous acceleration if the position of a particle is given as a function of time.
   f. Recognize that the equations of kinematics apply when motion occurs under constant acceleration
   g. Describe what is meant by a body in free fall. Recognize that the equations of kinematics apply directly to a freely falling object where the acceleration is given by $a = - g$.
   h. Apply the equations of kinematics to any situation where the motion occurs under constant acceleration.
   i. Describe the displacement, velocity, and acceleration of a particle moving in the x-y plane.
   j. Explain the nature of the acceleration of a particle moving in a circle with constant speed.
   k. Describe the components of acceleration for a particle moving on a curved path, where both the magnitude and direction of v are changing with time.
   l. Discuss the concept of force and the effect of an unbalanced force on the motion of a body.
   m. Discuss the concepts of mass and inertia and understand the difference between mass and weight.
   n. Become familiar with the SI units of force (N), mass (kg) and acceleration (m/s2), and the relation of these units to the English units.
   o. Discuss the nature of the fundamental forces in nature (gravitational, electromagnetic and nuclear) and characterize the properties and relative strengths of these forces.
8. Explain the physical concepts of energy and momentum, the conservation of both concepts, and how they relate to different physical systems.
   a. Define the work done by a constant force.
   b. Recognize that the work done by a force can be positive, negative, or zero, and describe at least one example of each case.
   c. Describe the work done by a force that varies with position.
   d. Define the kinetic energy of an object of mass m moving with a speed v.
   e. Relate the work done by the net force on an object to the change in kinetic energy. The relation $W = \Delta K = K_f - K_i$ is called the work - energy theorem.

f. Define the concepts of average power and instantaneous power (the time rate of doing work)
g. Discuss the properties of conservative and non-conservative forces.
h. Explain the distinction between kinetic energy, potential energy, and the total mechanical energy of a system.
i. State the law of conservation of mechanical energy, noting that mechanical energy is conserved only when conservative forces act on a system.
j. Compute the potential energy function associated with a conservative force such as the force of gravity and the spring force.
k. Recognize that the gravitational potential energy function, $U_g = mgy$, can be positive, negative or zero, depending on the location of the coordinate system used to measure y.
l. Recognize that the spring potential energy function, $Us = \frac{1}{2}kx^2$, is either positive or zero.
m. Explain the concept of linear momentum of a particle and the relation between the resultant force on a particle and the time rate of change of its momentum.
n. Recognize that the impulse of a force acting on a particle over some time interval equals the change in momentum of the particle, and understand the impulse approximation which is useful in treating collisions.
o. Recognize that the linear momentum of any isolated system is conserved.
p. Describe and distinguish the two types of collisions that can occur between two particles, namely elastic and inelastic collisions.
q. Recognize that a perfectly inelastic collision is an inelastic collision in which the colliding particles stick together after the collision.
r. Understand the fact that conservation of linear momentum applies not only to head-on collisions (one-dimensional) but also to glancing collisions (two or three dimensional).

9. Explain the properties and motions of rigid bodies.
    a. Explain and describe the concept of center of mass as applied to a collection of particles or a rigid body.
    b. Define the angular velocity and angular acceleration of a particle or body rotating about a fixed axis.
    c. Recognize that if a body rotates about a fixed axis, every particle on the body has the same angular velocity and angular acceleration.
    d. Note the similarity between the equations of rotational kinematics and those of linear kinematics.
    e. Describe and understand the relationships between linear speed and angular speed ($v = r\omega$), and between linear acceleration and angular acceleration.
    f. Calculate the moment of inertia I of a system of particles or a rigid body about a specific axis, including use of the parallel-axis theorem.
    g. Describe and illustrate the concept of torque associated with a force.
    h. Discuss the work-energy theorem as it is applied to a rotating rigid body.
    i. Define the angular momentum L of a particle moving with a velocity v relative to a specified point, and the torque τ acting on the particle relative to that point.

j. Describe and apply the total angular momentum of a system of particles and a rigid body rotating about a fixed axis.
k. Describe the two necessary conditions of equilibrium for a rigid body.
l. Locate the center of gravity of a system of particles or a rigid body and understand the difference between center of gravity and center of mass.

10. Describe and use Newton's universal law of gravity.
    a. State Kepler's three laws of planetary motion and recognize that the laws are empirical in nature, based on astronomical data.
    b. Recognize that Kepler's second law is a consequence of conservation of angular momentum and the central nature of the gravitational force.
    c. Describe the total energy of a planet or earth satellite moving in a circular orbit about a large body located at the center of motion.
11. Analyze and solve problems for objects that exhibit Simple Harmonic Motion.
    a. Sketch or identify a graph of displacement as a function of time, and determine from such a graph the amplitude, period, and frequency of the motion.
    b. Write down an appropriate expression for displacement of the form $A\ \sin(\omega t)$ or $A\ \cos(\omega t)$ to describe the motion.
    c. Find an expression for velocity as a function of time.
    d. State the relations between acceleration, velocity, and displacement, and identify points in the motion where these quantities are zero or achieve their greatest positive and negative values.
    e. State and apply the relation between frequency and period.
    f. Recognize that a system that obeys a differential equation of the form $dx^2/dt^2=w^2x$ must execute simple harmonic motion, and determine the frequency and period of such motion.
    g. State how the total energy of an oscillating system depends on the amplitude of the motion, sketch or identify a graph of kinetic or potential energy as a function of time, and identify points in the motion where this energy is all potential or all kinetic.
    h. Calculate the kinetic and potential energies of an oscillating system as functions of time, sketch or identify graphs of these functions, and prove that the sum of kinetic and potential energy is constant.
    i. Calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity.
    j. Develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.
    k. Apply the expression for the period of oscillation of a mass on a spring.
    l. Analyze problems in which a mass hangs from a spring and oscillates vertically or horizontally.
    m. State what approximation must be made in deriving the period.
    n. Analyze the motion of a simple, torsional or physical pendulum

Competencies:

Scientific Reasoning: Upon the completion of this course, students should be able to:

- Explain the methods of scientific inquiry that lead to the acquisition of knowledge. Such methods include observations, testable hypotheses, logical

inferences, experimental design, data acquisition, interpretation, and reproducible outcomes.

- Apply scientific methods to investigate real-world phenomena, and routine and novel problems. This includes data acquisition and evaluation, and prediction.
- Represent scientific data symbolically, graphically, numerically, and verbally.
- Interpret scientific information and draw logical references from representations such as formulas, equations, graphs, tables, and schematics.
- Evaluate the results obtained from scientific methods for accuracy and/or reasonableness

Scientific Knowledge: Upon the completion of this course, students should be able to:

- Communicate using appropriate scientific terminology.
- Use representations and models to communicate scientific knowledge and solve scientific problems.
- Plan and implement data collection strategies appropriate to a particular scientific question.
- Articulate the reasons that scientific explanations and theories are refined or replaced.
- Evaluate the quality of scientific information on the basis of its source and the methods used to generate it.