OSC016 - CALCULUS-BASED PHYSICS I (WITH LABS)

4-5 Semester Hours

Co-requisites: Calculus-1

Related TAGs: Biology, Chemistry, Civil/Construction Engineering Technology, Electrical Engineering Technology, Mechanical Engineering Technology

Required Components include:

I. **Experiment**
II. **Kinematics**
III. **Dynamics**
IV. **Conservation Laws**

Optional Components include:

V. **Waves**
VI. **Fluids**
VII. **Heat & Thermodynamics**

In order for a course to be approved for OSC016- Calculus Based Physics I (with labs), all of the following must be met:

1) All "Required Component" student learning outcomes (SLOs) 1-4 must be met and one out of the three "Optional Component" SLO's 5-7 must be met.
2) All student learning outcomes (SLOs) embedded within a "Required Component" area are required to meet the entirety of the required component area. This is also true for the "Optional Component" SLO's. All SLO's embedded within the optional component are required to meet the entirety of the optional component area however, this is only true when an optional component area is selected by an institution.

Required Components

1. **Experiment**:
   The successful Calculus-Based Physics I (with lab) student will be able to:

   1a. Collect data from experiments they have performed, assess its validity, estimate errors, propagate errors, and interpret the physical meaning of the data for experiments that relate to the materials needed for the other outcomes in this calculus physics course.
   1b. Meet the guidelines for the Natural Sciences Laboratory Requirement for the Ohio Transfer 36.

Sample tasks

- Demonstrate an understanding of the validity and meaning of data by writing lab reports with data-supported conclusions.
- Represent and analyze data in various forms (e.g., graphs, tables), as well as recognize trends and patterns in data accounting for scatter and outliers.
- Implement and design basic experimental procedures including the choice, variation, and control of variables, as well as recognize the existence of uncertainty and an estimate of the precision of the measurements.
- Analyze data through the use of various mathematical approaches including vector

manipulation and analysis, trigonometry, algebra, and calculus.
- Validate physics models and principles through collection of real physical data obtained by hands-on measurement.
- Recognize group work is a preferred environment.
- Error propagation using calculus: for example, a measurement of the acceleration due to gravity from the motion of a simple pendulum.

2. **Kinematics**:
The successful Calculus-Based Physics I (with lab) student will be able to:

2a. Make accurate verbal, graphical, and mathematical descriptions of rotational motion and translational motion in one and two dimensions.
2b. Use calculus and graphical methods to link displacement, velocity, and acceleration.
2c. Solve 1D kinematic problems with constant linear and angular acceleration.
2d. Solve 2D projectile motion problems where the starting point and ending points are at different heights.
2e. Relate the motion of two objects relative to each other.

Sample tasks

- Find the final speed of a particle dropped from rest at a given height.
- Calculate the launch speed and angle of a projectile for the projectile to hit a target at a a specified horizontal and vertical displacement.
- Sketch graphs of speed versus time and velocity versus time for an object that is thrown upwards and returns to the starting point.
- Sketch graphs of position versus time for the same motion using two sets of coordinate axes (different origins and/or positive directions).
- Determine the distance traveled by a rolling disk given the disk radius, angular acceleration, initial speed and elapsed time.
- Calculate the number of revolutions made by a spinning wheel slowing to a stop at a constant rate.
- Given a graph of velocity vs. time for a particle in moving in one dimension, interpret the physical meanings of the graph's slope and intercept, then qualitatively sketch the position vs time or acceleration vs time graphs for the same interval.
- Determine the horizontal displacement for a projectile launched with an initial velocity (magnitude and direction) given the total vertical displacement.
- Explain the difference between average velocity and average speed for motion in 1 and 2 dimensions.
- Describe the motion of an object accelerating in both the horizonal and vertical direction.
- Describe the 1d motion of an object accelerating at a non-constant rate.
- Find the position of an object given the velocity versus time and the initial position.

3. **Dynamics**:
The successful Calculus-Based Physics I (with lab) student will be able to:

3a. Use Newton's laws of motion (1st, 2nd, and 3rd) to explain or predict the motion of translating objects in both one and two dimensions and with and without friction.
3b. Use Newton's laws of motion explain or predict the motion of rotating objects including rolling motion.

3c. Use Newton’s Laws to explain or predict when an object is at rest or in motion at constant velocity in both one and two dimensions and with and without friction.
3d. Determine the center of mass of extended objects in one, two- and three-dimensions utilizing symmetry and calculation.
3e. Explain and predict the change in momentum of particles subject to a variable force.
3f. Determine the moment of inertia of rigidly connected masses about an arbitrary axis.
3g. Relate the torque about the rotation axis of an object to the change in angular momentum and/or rotational kinetic energy of the object.
3h. Use the parallel axis theorem in the solution of problems of extended objects of simple symmetries rotating about an arbitrary axis.

Sample tasks

- Determine the acceleration of blocks connected by strings without and without pulleys, and find the tensions in the strings.
- Determine the acceleration of blocks on sloping surfaces and the tension in the rope connecting the blocks.
- Determine the minimum coefficient of static friction needed to prevent a car from slipping as it travels around a circular track at constant speed.
- Determine the location of a fulcrum to balance an extended object. For a cord wound around a circular (cylindrical) object and a mass tied to the cord, predict how the angular acceleration depends on the moment of inertia of the circular (cylindrical) object. of a uniform disk differs from a uniform hoop when the mass is released.
- Analyze a system of three blocks in contact while being pushed across a smooth/rough level table, making use of free body diagrams and Newton's laws of motion.
- Draw free body diagrams of an object placed on the floor of a rising elevator based on a velocity-time graph of the elevator’s motion.
- Determine the frictional force that acts on an object at rest while it is being pulled with a constant force,
- Explain why objects on the seat of a car will slide forward when the car abruptly slows down.
- Draw a free body diagram of an object falling in air as it approaches terminal speed.
- For a cylinder on an incline predict how the angular acceleration depends on the moment of inertia of the cylinder when the cylinder is released from rest.
- Find the acceleration of an object whose speed is increasing as it follows a circular path.
- Determine the net force on objects due to gravity at distances far from the surface of the Earth.
- Determine the components of force on an object suspended from at least two wires.
- Determine the components of force on an extended object hanging from a pole, and on the pole.
- Describe the motion (position, velocity, acceleration) of a simple pendulum in regard to length and frequency.
- Describe the motion (position, velocity, and acceleration) of a mass connected to one or more springs (horizontal and vertical).
- Describe the motion (position, velocity, and acceleration) of a physical pendulum.
- Apply Newton’s second law for translational and rotational motion for an object (sphere and cylinder) rolling down an incline plane without slipping.
- Describe the rebounding of a rotating billiard ball off a rigid wall.
- Describe the motion [both translation and rotation] of a spool [with inner and outer radius r and R, respectively] when it is pulled by a string at an arbitrary angle.

- Calculate the torque (vector) exerted on an extended object when forces are applied at different points and at different directions.
- Describe the direction of torque for rotating systems as in the direction of precession for a spinning wheel supported at the end of its axle.
- Calculate the torque vector in terms of the force and position vectors.
- Calculate the angular momentum vector in terms of the momentum and position vectors.
- Describe the vector character of Newton's second law for rotation.
- Describe precession of a spinning object in terms of the vector character of Newton's second law for rotation.

4. **Conservation Laws**:
The successful Calculus-Based Physics I (with lab) student will be able to:

4a. Explain and predict the change in motion of translating, rotating, and rolling objects using Conservation of Energy.
4b. Calculate the work done on particles by 1 and also by 2-dimensional forces that may be constant or variable in position.
4c. Describe and evaluate the change in translational motion for a group of particles in one and two dimensions using the conservation of momentum.
4d. Determine changes to rotational motion using the conservation of angular momentum.
4e. Diagram and predict the velocities of particles participating in elastic and inelastic collisions in one and two dimensions.

Sample tasks

- Compare the speeds of a roller-coaster at various elevations along its track, assuming that friction and air resistances are negligible and determine if the roller coaster cart remains on the track at peak positions of circular arcs.
- Analyze a collision in the center of mass frame.
- Explain why rolling objects of the same mass and radius, but different shapes, don't all reach the bottom of a ramp at the same time.
- Calculate the height necessary for a disk rolling down an incline to achieve the same speed at the bottom of the incline as a sphere achieves rolling down the same incline at a given height.
- Determine the outcome of a one-dimensional perfect inelastic collision given the masses and the initial velocities.
- Decide whether or not a one-dimensional collision is elastic given the initial speeds of the masses, and the final speed of one of the objects.
- Predict whether a rotating platform will speed up or slow down as a passenger walks inward or outward along the platform's radius.
- Predict the escape velocity from the surface of the Earth or another planet.
- Determine the energy required to place a satellite into a circular orbit around the Earth or another planet.
- Describe the motion of a simple pendulum or mass and a spring via conservation of energy.
- Describe the motion of an object travelling in a tunnel drilled through the Earth.
- Obtain a force vector function from a potential energy function.
- Predict the (translational/angular) velocity of objects after they collide with each other using the laws of conservation of translational/rotational momentum.
- Calculate the change in rotational speed of a merry-go-round when a child jumps onto it along a

tangent to the edge and perpendicular to the edge.

- Determine the work done by one force on an object that moves in a specified straight line when the force is a position-dependent force in the x-y plane.

Optional Components

5. **Waves**:

The successful Calculus-Based Physics I (with lab) student will be able to:

5a. Explain or predict mechanical wave phenomena in terms of frequency, wavelength, wave speed.
5b. Use superposition to determine the resultant waveform due to the interference of two longitudinal mechanical or transverse mechanical waves.
5c. Describe standing wave patterns and how their confinement determines the allowed wavelengths.
5d. Describe and predict the addition of two waves.
5e. Solve problems where the observed frequency of sound is affected by the motion of the source and/or the receiver relative to the medium (Doppler effect).
5f. Determine the intensity of sound at some distance from its source, including the corresponding decibel levels.

Sample tasks

- Explain how an understanding of transverse and longitudinal earthquake waves helps us understand the makeup of the Earth, specifically that there is solid core surrounded by a liquid core, surrounded by the solid Earth.
- Calculate the observed frequency for a moving observer given the speed of the observer towards or away from the sound source and the frequency of the sound produced by the source.
- Compare the maximum speed of a traveling sine wave along a string to the maximum speed of a point on the string given the density of the string, the tension in the string, and the emitted frequency of the source.
- Find the resonant frequencies of the standing waves for an open pipe and a closed pipe of the same length, given the speed of sound in air.
- Adding two incoherent sources of sound that are of very different intensities.
- Relate the change in the sound intensity and decibel level when the number of incoherent sound sources is increased or decreased.
- Find max/min intensity in front of identical coherent loudspeakers.
- Explain the positions of nodes and antinodes in standing sound waves and the difference between the pressure maxima and displacement maxima.
- Determine the wavelength, frequency, wave speed, amplitude, and phase of a wave by inspecting a solution to the wave equation.
- Write the solution for a wave on a string in the form $f(x,t)=A\sin(kx-\omega t+\delta)$ given the tension, mass density of the string, initial conditions for a point on the string and the frequency of the disturbance.

6. **Fluids**:

The successful Calculus-Based Physics I (with lab) student will be able to:

6a. Describe how the pressure in a fluid varies as a function of depth in terms of the pressure relative to the surface of the fluid and the absolute pressure in the fluid.
6b. Predict whether an object will sink or float in a fluid.
6c. Predict the variation in pressure as an incompressible fluid flows though pipes of varying diameter and height.
6d. Predict the effects of friction or viscosity on fluid flow.
6e. Solve problems involving surface tension and capillary action.

Sample tasks

- Determine the force exerted by the atmosphere on the palm of a hand.
- Explain why the pressure on a swimmer's eardrum increases as the swimmer moves downward.
- Predict the maximum load a raft can support without sinking in water.
- Explain the physics underlying hydraulic lifts.
- Predict the relative velocities of a fluid at several points along a pipe with varying diameter.
- Calculate the pressure required to push a fluid through a pipe from a lower position to an open storage tank on top of a hill.
- Describe how the pressure depends on height for a static fluid [e.g., exponential atmosphere].
- Describe the time-dependence of the flow rate of fluid through a pipe that is inserted at the bottom of a container.
- Calculate the pressure difference across a spinning ball [Magnus effect].

7. **Heat & Thermodynamics**:
The successful Calculus-Based Physics I (with lab) student will be able to:

7a. Describe the effect of heat on the properties of materials including phase changes.
7b. Describe/predict the transfer of energy between a system and its environment using the first law of thermodynamics.
7c. Predict a system's state variables using the ideal gas laws.
7d. Link the temperature of matter and with kinetic energy of molecules of matter.
7e. Predict the efficiency of a heat engine or the coefficient of performance of a refrigerator and compare this to a Carnot cycle operating between the same max/min temperatures.
7f. Relate the efficiency of a heat engine to the second law of thermodynamics.
7g. Identify various heat transfer processes [conduction, convention, and radiation] and how they depend on physical properties.

Sample tasks

- Characterize the difference between *temperature* and *heat*.
- Calculate the temperature rise required to make a copper rod expand by 1 mm.
- Given the coefficients of linear expansion of two metals, predict the bending of a heated bimetallic strip.
- Given the initial temperature and pressure in an inflated tire, determine whether the tire's pressure will exceed its maximum safe level when heated to a specific temperature.
- Calculate the heat required to bring a gallon of room-temperature water to boil, and then the heat required to completely evaporate the water.
- Describe the microscopic processes when a solid melts.
- Predict whether it would take more heat to melt two different materials with the same mass the same mass of solid copper or water ice, if both are already at their melting points.

- Classify a given process as either reversible or irreversible, based on heat flow.
- Use the concepts of heat, work, and internal energy to describe the operation of a heat engine.
- Relate processes in a P-V diagram to the processes in P-T and V-T diagrams.
- Calculate the work done by a gas and the heat added/removed to a cyclic process, and calculate the corresponding efficiencies, or coefficients of performance.
- Explain or describe the heat exchange during phase changes.
- Predict the pressure at the surface of the Earth for an atmosphere with a density that varies with height.
- Predict the equilibrium temperature of the Earth due to irradiation by the sun.

OSC017 - CALCULUS-BASED PHYSICS II (WITH LABS)

4-5 Semester Hours

Pre-requisite: OSC016- College Calculus-Based Physics I (with labs)

Related TAGs: Chemistry, Civil/Construction Engineering Technology, Electrical Engineering Technology, Mechanical Engineering Technology

Required Components include:

- **I. Experiment**
- **II. Electromagnetism**
- **III. Electrical Devices and Circuits**

Optional Components include:

- **IV. Geometric and Physical Optics**
- **V. Special Relativity**
- **VI. Quantum Physics**

In order for a course to be approved for OSC017- Calculus Based Physics II (with labs), all of the following must be met:

1) All “Required Component” student learning outcomes (SLOs) 1-3 must be met and one out of the four “Optional Component” SLO’s 4-7 must be met.
2) All student learning outcomes (SLOs) embedded within a “Required Component” area are required to meet the entirety of the required component area. This is also true for the “Optional Component” SLO’s. All SLO’s embedded within the optional component are required to meet the entirety of the optional component area however, this is only true when an optional component area is selected by an institution.

<u>Required Components</u>

1. **Experiment**:

The successful Calculus-Based Physics II (with lab) student will be able to:

1a. Collect data from experiments they have performed, assess its validity, estimate errors, propagate errors, and interpret the physical meaning of the data for experiments that relate to the materials needed for the other outcomes in this calculus physics course.

1b. Meet the guidelines for the Natural Sciences Laboratory Requirement for the Ohio Transfer 36.

Sample tasks

- Demonstrate an understanding of how to write lab reports including data-supported conclusions.
- Represent and analyze data in various forms (e.g., graphs, tables), as well as recognize trends and patterns in data accounting for scatter and outliers.
- Implement and design basic experimental procedures including the choice, variation and control of variables, as well as recognize the existence of uncertainty and an estimate of the precision of the measurements.
- Analyze data through the use of various mathematical approaches including vector manipulation and analysis, trigonometry, algebra, and calculus.
- Validate physics models and principles through collection of real physical data obtained by hands-on measurement.
- Recognize group work is a preferred environment.
- Error propagation using calculus.

2. **Electromagnetism:**
The successful Calculus-Based Physics II (with lab) student will be able to:

2a. Explain and predict the motion of point charges in terms of electromagnetic fields and forces, electric potential, and energy conservation laws.
2b. Determine the electric field and potential of three point charges not in a straight line.
2c. Determine the motion of a charged particle in a uniform electric field.
2d. Determine the electric field from a continuous distribution of charge such as a line, plane, ring, or disk.
2e. Use Gausses law to determine the electric field of a charged sphere or cylinder.
2f. Determine the magnetic field from a current carrying conductor.
2g. Find the electric field from an electric potential function.
2h. Explain and predict the induced electric current and the forces present in a loop of wire due to a changing magnetic flux.
2i. Explain or describe the propagation, transmission, and detection of electromagnetic waves.

Sample tasks

- Calculate the electric field and potential for point charge, given the position of the charge and the field location.
- Describe the relationship of the electric field between the plates of a parallel-plate capacitor to the voltage across and distance between the plates.
- Calculate the force between two or more-point charges at given positions.
- Determine the net electric field at a chosen location due to several point charges.
- Find locations of zero electric field for an electric from two electric point charges
- Given a point charge magnitude and position, find the electric field at chosen positions and the force that would be experienced by a second charge at the chosen field positions.
- Use Gauss' law to determine the induced charge on the inner surface of a conducting cylinder that surrounding a line charge.
- Use Gauss's law to describe the electric field between the inner and outer conductors of a coaxial cable?

- Explain the electric field and electric potential inside and outside spherical and cylindrical metal shells.
- Use Gauss's law to calculate the electric field and electric potential in the vicinity of symmetric charged objects.
- Calculate the electric field near a line segment of charge.
- Use vector superposition to determine the electric field at a point in the x-y plane near a point charge and a line segment of charge located in the plane.
- Sketch the magnetic field lines produced by a bar magnet, a long wire, and a solenoid.
- Find the force per unit length and the direction for a vertically upward current immersed in a magnetic field of specified strength which is directed towards the East.
- Explain how a velocity selector works consisting of perpendicular magnetic and electric fields.
- Calculate the separation of charged isotopes in a mass spectrometer.
- Predict the direction and magnitude of the magnetic force on a charge traveling in a specified direction through a magnetic field and explain how the right-hand rule is used for such questions.
- Predict the direction of an induced current in a coil by changes in the magnetic flux.
- What current flows through a resistor connecting parallel horizontal rails separated by a specified distance and immersed in a vertical magnetic field when a rod spanning the rails is pulled at a speed of v along the rails.
- Calculate the magnetic field due to simple geometries of three or more parallel wires.
- Explain the induced voltage across a conducting rod traveling through a magnetic field.
- Explain how charged particles are accelerated in a betatron.
- Determine the electric field or magnetic field intensity at some distance from a dipole.
- Find the intensity of a polarized electromagnetic wave that passes through two polarizers not at right angles to each other.
- Use Ampere's law to calculate the magnetic field at the center of a loop of wire or a solenoid.
- Use electromagnetic laws to calculate the forces on and the velocity of a projectile in an electromagnetic gun.
- Calculate the magnetic field inside and outside a long wire with radial current density.
- Use the Biot-Savart law to determine the magnetic field on the axis of a current loop not at the center of the loop.
- Use Faraday's and Lenz' laws to find the magnitude and direction of the current induced in a loop immersed in a time-varying magnetic field as a function of the loop's angle.
- Describe the electric and magnetic fields associated with charging and discharging of a parallel-plate capacitor in terms of a displacement current.
- Relate the permittivity and permeability of a medium to the speed of light in that medium.

3. **Electrical devices and circuits**:

The successful Calculus-Based Physics II (with lab) student will be able to:

3a. Determine the steady state potential differences across and electric current in each component in a circuit containing a battery and several resistors in parallel and series.

3b. Determine the equivalent resistance for combinations of at least three resistors in parallel and in series.

3c. Determine the equivalent capacitance for combinations of at least three capacitors in parallel and in series.

3d. Explain or predict the currents and voltage drops in a circuit containing a battery, resistors, and capacitors for both short and long times.
3e. Explain or predict the currents and voltage drops in a circuit containing a battery, resistors, and inductors for both short and long times.
3f. Explain or predict the time varying and asymptotic electrical properties of capacitors and inductors driven by an AC generator.

Sample tasks

- Given a circuit block containing capacitors arranged in series and parallel configurations, reduce the capacitors to a single equivalent capacitance.
- Reduce a circuit block containing resistors in series and parallel configurations to a single equivalent resistance.
- Calculate the voltage across a current-carrying resistor.
- Follow the phase of currents in a series LRC circuit.
- Use Kirchhoff's laws to find the currents through each component of a two-loop circuit with several resistors and two or more batteries.
- Compare the costs of running different electrical devices.
- Calculate the resistance of a sample given the length, cross-sectional area, and resistivity (or conductivity) of the sample.
- Calculate the work necessary to pull capacitor plates from each other and calculate the force between plates.
- Calculate the work done on a dielectric slab moving in or out from the plates of a capacitor.
- Calculate the energy stored in capacitors and inductors.
- Calculate the density of energy stored in a capacitor and an inductor.
- Determine the current density in a material and relate it to the density of charge carriers.

Optional Components

4. **Geometric and Physical Optics:**
The successful Calculus-Based Physics II (with lab) student will be able to:

4a. Explain or predict the behavior of electromagnetic waves interacting with mirrors, transparent media, thin lenses, slits, and gratings.
4b. Describe the interference, diffraction, and dispersion of light and calculate the separation of features seen in the patterns formed by these processes.
4c. Use the ray model of light to solve problems with plane and spherical mirrors, prisms, and thin lenses.
4d. Use the wave description of light to predict interference from a thin film.
4e. Use wave description of light to predict interference from single, double, and multiple slits and diffraction gratings.

Sample tasks

- Determine the critical angle of a prism immersed in a medium.
- Use ray tracing to explain image formation by spherical mirrors and thin lenses.
- Predict the total number of maxima obtained when light of a specific wavelength is incident on a diffraction grating.
- Use Snell's law to find the apparent depth of an object immersed in a transparent medium.

- Given the focal length of a thin lens and the object distance; locate the image, identify it as real or virtual, and calculate its magnification.
- Locate the image of an object placed in front of a mirror of specified radius.
- Find the location and size of an object that produces a certain real/virtual image by a spherical mirror using either algebraic or ray-tracing methods.
- Determine the refractive index of a material from the Brewster angle.
- Locate and describe the final image of an object which has been placed in front of an optical system consisting of two lenses separated by a specified distance.
- Explain why white light separates into its color components when it passes through a prism.
- Calculate the speed of light traveling through water, given the index of refraction of water.
- Locate the position of the first bright fringe of monochromatic coherent light passing through a double slit relative to the central axis and on a screen at a given distance.
- Describe the differences between diffraction and interference in a double slit pattern.
- Analyze the resolving power of telescopes and other (optical) systems.

5. **Special Relativity**:
   The successful Calculus-Based Physics II (with lab) student will be able to:

5a. Explain and predict the behavior and character of objects moving at high speeds in terms of the principles of special relativity.
5b. State the two postulates of the special theory of relativity and apply them to objects traveling close to the speed of light.
5c. Relate the key result of the Michelson-Morley experiment to the postulates of special relativity.
5d. Apply the equations of Lorentz transformation and relate the spatial and temporal intervals observed by moving and stationary observer.
5e. Describe the "twin paradox."
5f. Apply the relativistic energy-momentum relationship.

Sample tasks

- Apply the energy-momentum relationship to the case of particles with zero mass and to particles with non-zero mass.
- Determine the observed length in Earth's reference frame of a spaceship traveling past an observer on Earth at a relative speed near the speed of light (say, 0.8*c*) and compare this to the length of the spaceship in the reference frame of the crew.
- Compare the time duration of a trip taken in a spaceship over a long distance at a speed near the speed of light in the reference frame of Earth to the time duration of the same trip in the reference frame of the crew on the ship. (Perhaps use a trip from Earth to the center of the galaxy at a speed of 0.95*c* in Earth's reference frame.)
- Calculate the kinetic energy and momentum of a proton or electron accelerated to a speed near *c* and compare these values to their Newtonian counterparts.
- Find the familiar expression of the kinetic energy of a particle with mass m from the binomial expansion of the relativistic energy.
- Calculate the rest mass of a rechargeable battery before and after it has been recharged.
- Calculate the frequency of EM waves observed by a moving/stationary observer when the source is moving/stationary [relativistic Doppler effect].
- Calculate the lifetime of a muon.

6. **Quantum Physics:**

The successful Calculus-Based Physics II (with lab) student will be able to:

6a. Understand the evidence of wave-like properties of particles [proton, electron…] and molecules [buckyball].
6b. Explain how the ultraviolet catastrophe is resolved by the quantization of energy.
6c. Relate the frequency-wavelength relation of EM waves to the energy-momentum relation of a photon.
6d. Relate the production and properties of photoelectrons to the particle-like property of light.
6e. Describe the intensity of light (EM waves) in terms of the number of photons per unit time and frequency (and/or wavelength) of photons.
6f. Relate the wave-like nature of an electron to its stationary state in a confining potential [particle in a box and hydrogen atoms].

Sample tasks

- Calculate the longest wavelength of light that can eject electrons from a metal with known work function.
- Relate the difference in incident light frequency and intensity with the energy and current of electrons ejected in the photoelectric effect.
- Find the wavelength of an electron with a specified momentum or kinetic energy (at speeds well below the speed of light).
- Calculate the energy and frequency of the photon emitted/absorbed as the electron makes a transition from n_i *to* n_f.. Determine the series (Lyman, Balmer, etc.) for a set of hydrogen spectral lines given the frequencies or wavelengths of the set.
- Estimate the size of an object for it to no longer exhibit significant wave-like behavior.
- Write down the possible electron configuration for a chosen atom realizing the unexpected changes that occur in stable orbital configurations.
- Describe how photons display both wave and particle behavior as they travel through a diffraction grating and onto a piece of photographic film. Compare the wavelength of an electron at a given speed to the wavelength of a visible photon and describe the diffraction limit of each as an illuminating beam for a microscope.
- Relate the resolving power of an electron microscope to the Heisenberg uncertainty principle.