Introduction: Forces in One Dimension

Unit: Forces in One Dimension

Topics covered in this chapter:

In this chapter you will learn about different kinds of forces and how they relate.

- *Newton's Laws* and *Types of Forces* describe basic scientific principles of how objects affect each other.
- *Gravitational Fields* introduces the concept of a force field and how gravity is an example of one.
- *Free-Body Diagrams* describes a way of drawing a picture that represents forces acting on an object.
- *Tension, Friction* and *Drag* describe situations in which a force is created by the action of another force.

One of the first challenges will be working with variables that have subscripts. Each type of force uses the variable ***F***. Subscripts will be used to keep track of the different kinds of forces. This chapter also makes extensive use of vectors.

Another challenge in this chapter will be to "chain" equations together to solve problems. This involves finding the equation that has the quantity you need, and then using a second equation to find the quantity that you are missing from the first equation.

AP® This unit is part of *Unit 2: Force and Translational Dynamics* from the 2024 AP® Physics 1 Course and Exam Description.

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Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

HS-PS2-3. Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

HS-PS2-10(MA). Use free-body force diagrams, algebraic expressions, and Newton's laws of motion to predict changes to velocity and acceleration for an object moving in one dimension in various situations.

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AP® Physics 1 Learning Objectives/Essential Knowledge (2024):

2.1.A: Describe the properties and interactions of a system.

2.1.A.1: System properties are determined by the interactions between objects within the system.

2.1.A.2: If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.

2.1.A.3: Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.

2.1.A.4: Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.

2.1.A.5: The internal structure of a system affects the analysis of that system.

2.1.A.6: As variables external to a system are changed, the system's substructure may change.

2.1.B: Describe the location of a system's center of mass with respect to the system's constituent parts.

2.1.B.1: For systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.

2.1.B.2: The location of a system's center of mass along a given axis can be calculated using the equation: $\vec{\boldsymbol{x}}_{cm} = \dfrac{\Sigma\, m_i \vec{\boldsymbol{x}}_i}{\Sigma\, m_i}$.

2.1.B.3: A system can be modeled as a singular object that is located at the system's center of mass.

2.2.A: Describe a force as an interaction between two objects or systems.

2.2.A.1: Forces are vector quantities that describe the interactions between objects or systems.

2.2.A.1.i: A force exerted on an object or system is always due to the interaction of that object with another object or system.

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2.2.A.1.ii: An object or system cannot exert a net force on itself.

2.2.A.2: Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.

2.2.B: Describe the forces exerted on an object or system using a free-body diagram.

2.2.B.1: Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.

2.2.B.2: The free-body diagram of an object or system shows each of the forces exerted on the object by the environment.

2.2.B.3: Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.

2.2.B.4: A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free-body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline.

2.3.A: Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object.

2.3.A.1: Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other.

2.3.A.2: Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.

2.3.A.3: Tension is the macroscopic net result of forces that segments of a string, cable, chain, or similar system exert on each other in response to an external force.

2.3.A.3.i: An ideal string has negligible mass and does not stretch when under tension.

2.3.A.3.ii: The tension in an ideal string is the same at all points within the string.

2.3.A.3.iii: In a string with nonnegligible mass, tension may not be the same at all points within the string.

2.3.A.3.iv: An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.

2.4.A: Describe the conditions under which a system's velocity remains constant.

2.4.A.1: The net force on a system is the vector sum of all forces exerted on the system.

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2.4.A.2: Translational equilibrium is a configuration of forces such that the net force exerted on a system is zero.

2.4.A.3: Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.

2.4.A.4: Forces may be balanced in one dimension but unbalanced in another. The system's velocity will change only in the direction of the unbalanced force.

2.4.A.5: An inertial reference frame is one from which an observer would verify Newton's first law of motion.

2.5.A: Describe the conditions under which a system's velocity changes.

2.5.A.1: Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.

2.5.A.2: acceleration of a system's center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force.

2.5.A.3: The velocity of a system's center of mass will only change if a nonzero net external force is exerted on that system.

2.6.A: Describe the gravitational interaction between two objects or systems with mass.

2.6.A.1.iii: The gravitational force on a system can be considered to be exerted on the system's center of mass.

2.6.A.2: A field models the effects of a noncontact force exerted on an object at various positions in space.

2.6.A.2.i: The magnitude of the gravitational field created by a system of mass *M* at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass *m* to the mass of the test object.

2.6.A.2.ii: If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s^2) is numerically equal to the magnitude of the gravitational field strength (in N/kg) at that location.

2.6.A.3: The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight.

2.6.B: Describe situations in which the gravitational force can be considered constant.

2.6.B.2: Near the surface of Earth, the strength of the gravitational field is $\vec{g} \approx 10\,\frac{\text{N}}{\text{kg}}$.

2.6.C: Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system.

2.6.C.1: The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.

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2.6.C.2: If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.

2.6.C.3: A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.

2.6.C.4: The equivalence principle states that an observer in a noninertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field.

2.7.A: Describe kinetic friction between two surfaces.

2.7.A.1: Kinetic friction occurs when two surfaces in contact move relative to each other.

2.7.A.1.i: The kinetic friction force is exerted in a direction opposite to the motion of each surface relative to the other surface.

2.7.A.1.ii: The force of friction between two surfaces does not depend on the size of the surface area of contact.

2.7.A.2: The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction.

2.7.A.2.i: The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact.

2.7.A.2.ii: Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.

2.8.A: Describe the force exerted on an object by an ideal spring

2.8.A.1: An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length.

2.8.A.2: The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law: $\vec{\boldsymbol{F}}_s = -k\Delta\vec{\boldsymbol{x}}$

2.8.A.3: The force exerted on an object by a spring is always directed toward the equilibrium position of the object–spring system.

Skills learned & applied in this chapter:

- Solving chains of equations.
- Working with material-specific constants (coëfficients of friction) from a table.
- Solving systems of equations (pulley problems).

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