Introduction: Energy, Work & Power

Unit: Energy, Work & Power

Topics covered in this chapter:

This chapter deals with the ability of a moving object (or potential for an object to move) to affect other objects.

- *Energy* describes different types of energy, particularly potential and kinetic energy.
- *Work* describes changes in energy through the application of a force over a distance.
- *Conservation of Energy* explains and gives examples of the principle that "energy cannot be created or destroyed, only changed in form".
- *Rotational Work* and *Rotational Kinetic Energy* describe how these principles apply in rotating systems.
- *Escape Velocity* describes the application of the conservation of energy to calculate the velocity need to launch an object into orbit.
- *Power* describes the rate at which energy is applied

New challenges in this chapter involve keeping track of the same quantity applied to the same object, but at different times.

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This unit is part of *Unit 3: Work, Energy, and Power* and *Unit 6: Energy and Momentum of Rotating Systems* from the 2024 AP® Physics 1 Course and Exam Description.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

HS-PS3-1. Use algebraic expressions and the principle of energy conservation to calculate the change in energy of one component of a system when the change in energy of the other component(s) of the system, as well as the total energy of the system including any energy entering or leaving the system, is known. Identify any transformations from one form of energy to another, including thermal, kinetic, gravitational, magnetic, or electrical energy, in the system.

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields.

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

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

3.1.A: Describe the translational kinetic energy of an object in terms of the object's mass and velocity.

3.1.A.1: An object's translational kinetic energy is given by the equation $K = \frac{1}{2}mv^2$.

3.1.A.2: Translational kinetic energy is a scalar quantity.

3.1.A.3: Different observers may measure different values of the translational kinetic energy of an object, depending on the observer's frame of reference.

3.2.A: Describe the work done on an object or system by a given force or collection of forces.

3.2.A.1: Work is the amount of energy transferred into or out of a system by a force exerted on that system over a distance.

3.2.A.1.i: The work done by a conservative force exerted on a system is path-independent and only depends on the initial and final configurations of that system.

3.2.A.1.ii: The work done by a conservative force on a system—or the change in the potential energy of the system—will be zero if the system returns to its initial configuration.

3.2.A.1.iii: Potential energies are associated only with conservative forces.

3.2.A.1.iv: The work done by a nonconservative force is path-dependent.

3.2.A.1.v: Examples of nonconservative forces are friction and air resistance.

3.2.A.2: Work is a scalar quantity that may be positive, negative, or zero.

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3.2.A.3: The amount of work done on a system by a constant force is related to the components of that force and the displacement of the point at which that force is exerted.

3.2.A.3.i: Only the component of the force exerted on a system that is parallel to the displacement of the point of application of the force will change the system's total energy.

3.2.A.3.ii: The component of the force exerted on a system perpendicular to the direction of the displacement of the system's center of mass can change the direction of the system's motion without changing the system's kinetic energy.

3.2.A.4: The work-energy theorem states that the change in an object's kinetic energy is equal to the sum of the work (net work) being done by all forces exerted on the object.

3.2.A.4.i: An external force may change the configuration of a system. The component of the external force parallel to the displacement times the displacement of the point of application of the force gives the change in kinetic energy of the system.

3.2.A.4.ii: If the system's center of mass and the point of application of the force move the same distance when a force is exerted on a system, then the system may be modeled as an object, and only the system's kinetic energy can change.

3.2.A.4.iii: The energy dissipated by friction is typically equated to the force of friction times the length of the path over which the force is exerted.

3.2.A.5: Work is equal to the area under the curve of a graph of $F_{||}$ as a function of displacement.

3.3.A: Describe the potential energy of a system.

3.3.A.1: A system composed of two or more objects has potential energy if the objects within that system only interact with each other through conservative forces.

3.3.A.2: Potential energy is a scalar quantity associated with the position of objects within a system.

3.3.A.3: The definition of zero potential energy for a given system is a decision made by the observer considering the situation to simplify or otherwise assist in analysis.

3.3.A.4: The potential energy of common physical systems can be described using the physical properties of that system.

3.3.A.4.ii: The general form for the gravitational potential energy of a system consisting of two approximately spherical distributions of mass (*e.g.,* moons, planets or stars) is given by the equation $U_g = -G\frac{m_1 m_2}{r}$.

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3.3.A.4.iii: Because the gravitational field near the surface of a planet is nearly constant, the change in gravitational potential energy in a system consisting of an object with mass *m* and a planet with gravitational field of magnitude *g* when the object is near the surface of the planet may be approximated by the equation $\Delta U_g = mg\Delta y$.

3.3.A.5: The total potential energy of a system containing more than two objects is the sum of the potential energy of each pair of objects within the system.

3.4.A: Describe the energies present in a system.

3.4.A.1: A system composed of only a single object can only have kinetic energy.

3.4.A.2: A system that contains objects that interact via conservative forces or that can change its shape reversibly may have both kinetic and potential energies.

3.4.B: Describe the behavior of a system using conservation of mechanical energy principles.

3.4.B.1: Mechanical energy is the sum of a system's kinetic and potential energies.

3.4.B.2: Any change to a type of energy within a system must be balanced by an equivalent change of other types of energies within the system or by a transfer of energy between the system and its surroundings.

3.4.B.3: A system may be selected so that the total energy of that system is constant.

3.4.B.4: If the total energy of a system changes, that change will be equivalent to the energy transferred into or out of the system.

3.4.C: Describe how the selection of a system determines whether the energy of that system changes.

3.4.C.1: Energy is conserved in all interactions.

3.4.C.2: If the work done on a selected system is zero and there are no nonconservative interactions within the system, the total mechanical energy of the system is constant.

3.4.C.3: If the work done on a selected system is nonzero, energy is transferred between the system and the environment.

3.5.A: Describe the transfer of energy into, out of, or within a system in terms of power.

3.5.A.1: Power is the rate at which energy changes with respect to time, either by transfer into or out of a system or by conversion from one type to another within a system.

3.5.A.2: Average power is the amount of energy being transferred or converted, divided by the time it took for that transfer or conversion to occur.

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3.5.A.3: Because work is the change in energy of an object or system due to a force, average power is the total work done, divided by the time during which that work was done.

3.5.A.4: The instantaneous power delivered to an object by the component of a constant force parallel to the object's velocity can be described with the derived equation.

6.1.A: Describe the rotational kinetic energy of a rigid system in terms of the rotational inertia and angular velocity of that rigid system.

6.1.A.1: The rotational kinetic energy of an object or rigid system is related to the rotational inertia and angular velocity of the rigid system and is given by the equation $K_r = \frac{1}{2} I\omega^2$.

6.1.A.1.i: The rotational inertia of an object about a fixed axis can be used to show that the rotational kinetic energy of that object is equivalent to its translational kinetic energy, which is its total kinetic energy.

6.1.A.1.ii: The total kinetic energy of a rigid system is the sum of its rotational kinetic energy due to its rotation about its center of mass and the translational kinetic energy due to the linear motion of its center of mass.

6.1.A.2: A rigid system can have rotational kinetic energy while its center of mass is at rest due to the individual points within the rigid system having linear speed and, therefore, kinetic energy.

6.1.A.3: Rotational kinetic energy is a scalar quantity.

6.2.A: Describe the work done on a rigid system by a given torque or collection of torques.

6.2.A.1: A torque can transfer energy into or out of an object or rigid system if the torque is exerted over an angular displacement.

6.2.A.2: The amount of work done on a rigid system by a torque is related to the magnitude of that torque and the angular displacement through which the rigid system rotates during the interval in which that torque is exerted.

6.2.A.3: Work done on a rigid system by a given torque can be found from the area under the curve of a graph of torque as a function of angular position.

6.5.A: Describe the kinetic energy of a system that has translational and rotational motion.

6.5.A.1: The total kinetic energy of a system is the sum of the system's translational and rotational kinetic energies. $K_{tot} = K_{trans} + K_{rot}$

6.5.B: Describe the motion of a system that is rolling without slipping.

6.5.B.1: While rolling without slipping, the translational motion of a system's center of mass is related to the rotational motion of the system itself with the equations: $\Delta x_{cm} = r\Delta\theta$, $v_{cm} = r\omega$, and $a_{cm} = r\alpha$.

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6.5.B.2: For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.

6.5.C: Describe the motion of a system that is rolling while slipping.

6.5.C.1: When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.

6.5.C.2: When a rotating system is slipping relative to another surface, the point of application of the force of kinetic friction exerted on the system moves with respect to the surface, so the force of kinetic friction will dissipate energy from the system.

6.6.A: Describe the motions of a system consisting of two objects interacting only via gravitational forces.

6.6.A.1: In a system consisting only of a massive central object and an orbiting satellite with mass that is negligible in comparison to the central object's mass, the motion of the central object itself is negligible.

6.6.A.2: The motion of satellites in orbits is constrained by conservation laws.

6.6.A.2.i: In circular orbits, the system's total mechanical energy, the system's gravitational potential energy, and the satellite's angular momentum and kinetic energy are constant.

6.6.A.2.ii: In elliptical orbits, the system's total mechanical energy and the satellite's angular momentum are constant, but the system's gravitational potential energy and the satellite's kinetic energy can each change.

6.6.A.2.iii: The gravitational potential energy of a system consisting of a satellite and a massive central object is defined to be zero when the satellite is an infinite distance from the central object.

6.6.A.3: The escape velocity of a satellite is the satellite's velocity such that the mechanical energy of the satellite-central-object system is equal to zero.

6.6.A.3.i: When the only force exerted on a satellite is gravity from a central object, a satellite that reaches escape velocity will move away from the central body until its speed reaches zero at an infinite distance from the central body.

6.6.A.3.ii: The escape velocity of a satellite from a central body of mass M can be derived using conservation of energy laws.

Skills learned & applied in this chapter:

- Conservation laws (before/after problems).