Chapter 7

1

ENERGY OF A SYSTEM

Mustafa Al-Zyout - Philadelphia University 29-Sep-25

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Lecture 02

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Work And Kinetic Energy

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Work - Kinetic Energy Theorem

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One possible result of work acting as an influence on a system is that the system changes its speed.

The system could possess kinetic energy.

A change in kinetic energy is one possible result of doing work to transfer energy into a system.

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Work - Kinetic Energy Theorem

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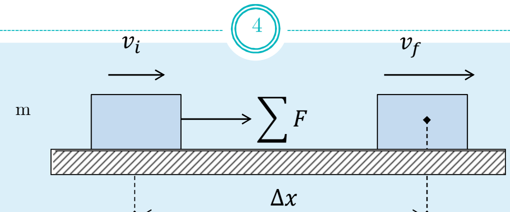

- Calculating the work:

$$W_{ext} = \int_{x_i}^{x_f} \sum F \, dx = \int_{x_i}^{x_f} m \, a \, dx = \int_{x_i}^{x_f} m \frac{dv}{dt} v \, dt = \int_{v_i}^{v_f} m \, v \, dv$$

$$W_{ext} = \frac{1}{2} m\left(v_f^2 - v_i^2\right)$$

$$W_{ext} = \frac{1}{2} m \, v_f^2 - \frac{1}{2} m \, v_i^2$$

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Work - Kinetic Energy Theorem

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Kinetic Energy: the energy of a particle due to its motion.

$$K = \frac{1}{2}mv^2$$

- m is the mass of the particle (kg)
- v is the speed of the particle (m/s)
- K is the kinetic energy
  - A scalar quantity: always positive.
  - SI units (Joule)
    - $1\ kg.m^2/s^2 = 1\ J$

Work - Kinetic Energy Theorem

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The $(W - \Delta K)$ theorem states that:

"When work is done on a system and the only change in the system is in its speed, the net work done on the system equals the change in kinetic energy of the system."

$$W_{ext} = \frac{1}{2}\,m\,v_f^2 - \frac{1}{2}\,m\,v_i^2$$

$$W_{ext} = K_f - K_i$$

$$W_{ext} = \Delta K$$

Work-Kinetic Energy Theorem

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- The speed of the system increases if the work done on it is positive.
  - The speed of the system decreases if the net work is negative.
    - Also valid for changes in rotational speed
- The work-kinetic energy theorem is not valid if other changes (besides its speed) occur in the system or if there are other interactions with the environment besides work.
- The work-kinetic energy theorem applies to the speed of the system, not its velocity.

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Work done by two constant forces, industrial spies

Saturday, 30 January, 2021 15:10

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The Figure shows two industrial spies sliding an initially stationary 225 kg floor safe a displacement of magnitude 8.5 m, straight toward their truck. The push $\vec{F}_1$ of spy 001 is 12 N, directed at an angle of 30° downward from the horizontal; the pull $\vec{F}_2$ of spy 002 is 10 N, directed at 40° above the horizontal. The magnitudes and directions of these forces do not change as the safe moves, and the floor and safe make frictionless contact.

- What is the work done on the safe by applied force $\vec{F}_1$?
- What is the work done on the safe by applied force $\vec{F}_2$?
- What is the work done on the safe by the normal force?
- What is the work done on the safe by the gravitational force?
- What is the net work done on the safe?
- The safe is initially stationary. What is its speed at the end of the 8.50 m displacement?

Solution

Because the forces are constant in both magnitude and direction, and we know the magnitudes and directions of the forces, we can use $w = Fd\cos\theta$.

The work done by $\vec{F}_1$ is:

$w_1 = F_1 d\cos\theta_1 = (12.0N)(8.50m)(\cos 30.0°) = 88.33J$

and the work done by $\vec{F}_2$ is:

$w_2 = F_2 d\cos\theta_2 = (10.0N)(8.50m)(\cos 40.0°) = 65.11J$

Thus, the net work W done on the safe by the two forces is the sum of the works they do individually:

$W = W_1 + W_2 = 88.33J + 65.11J = 153.4J$

During the 8.50 m displacement, therefore, the spies transfer 153 J of energy to the kinetic energy of the safe.

Solution

$W_g = mgd\cos 90° = mgd(0) = 0$

$W_N = F_N d\cos 90° = F_N d(0) = 0$

We should have known this result. Because these forces are perpendicular to the displacement of the safe, they do zero work on the safe and do not transfer any energy to or from it.

Solution

The speed of the safe changes because its kinetic energy is changed when energy is transferred to it by $\vec{F}_1$ and $\vec{F}_2$. We relate the speed to the work done by $W = \Delta K$.

$$W = K_f - K_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

The initial speed v_i is zero, and we now know that the work done is 153.4 J. Solving for v_f and then substituting known data, we find that

$$v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2(153.4J)}{225kg}} = 1.17m/s$$

Work done by a constant force in unit-vector notation

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During a storm, a crate is sliding across a slick, oily parking lot through a displacement $\Delta\vec{r} = (-3\hat{\imath})\,m$ while a steady wind pushes against the crate with a force $\vec{F} = (2\hat{\imath} - 6\hat{\jmath})\,N$. If the crate has a kinetic energy of 10 J at the beginning of displacement , what is its kinetic energy at the end?

Solution

Because the wind force is constant ("steady") in both magnitude and direction during the displacement, and we know $\vec{F}$ and $\vec{d}$ in unit-vector notation, we can use $w = \vec{F} \cdot \vec{d}$.

$W = \vec{F} \cdot \vec{d} = [(2.0N)\hat{\imath} + (-6.0N)\hat{\jmath}] \cdot [(-3.0m)\hat{\imath}]$
$W = (2.0N)(-3.0m)\hat{\imath} \cdot \hat{\imath} + (-6.0N)(-3.0m)\hat{\jmath} \cdot \hat{\imath}$
$\quad = (-6.0J)(1) + 0 = -6.0J$

Thus, the force does a negative 6.0 J of work on the crate, transferring 6.0 J of energy from the kinetic energy of the crate.

Using the work–kinetic energy theorem:
$K_f = K_i + W = 10J + (-6.0J) = 4.0J$
Less kinetic energy means that the crate has been slowed.

Work done by two constant force

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A $6\,kg$ block initially at rest is pulled to the right along a frictionless, horizontal surface by a constant horizontal force of $12\,N$. Find the block's speed after it has moved $3\,m$.

Solution

The net external force acting on the block is the horizontal 12-N force. Use the work–kinetic energy theorem for the block, noting that its initial kinetic energy is zero:

$$W_{ext} = K_f - K_i = \frac{1}{2}mv_f^2 - 0 = \frac{1}{2}mv_f^2$$

Solve for v_f and use $W_{ext} = F\Delta x$ for the work done on the block by $\vec{F}$:

$$v_f = \sqrt{\frac{2W_{ext}}{m}} = \sqrt{\frac{2F\Delta x}{m}}$$

Substitute numerical values:

$$v_f = \sqrt{\frac{2\ 12\text{N}\ 3.0\text{m}}{6.0kg}} = 3.5m/s$$

Suppose the magnitude of the force in this example is doubled to $F' = 2F$. The (6 kg) block accelerates to (3.5 m/s) due to this applied force while moving through a displacement $\Delta x'$. How does the displacement $\Delta x'$ compare with the original displacement Δx?

In both cases, the block experiences the same change in kinetic energy ΔK.

$$W_{ext} = F'\Delta x' = \Delta K = F\Delta x$$

$$\Delta x' = \frac{F}{F'}\Delta x = \frac{F}{2F}\Delta x = \frac{1}{2}\Delta x$$