

Chapter 7

1

ENERGY OF A SYSTEM

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29-Sep-25

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Lecture 01

2

Work

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Introduction to Energy

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- A variety of problems can be solved with Newton's Laws and associated principles.
- Some problems that could theoretically be solved with Newton's Laws are very difficult in practice.
 - These problems can be made easier with other techniques.
- The concept of energy is one of the most important topics in science and engineering.
- Every physical process that occurs in the Universe involves energy and energy transfers or transformations.
- Energy is not easily defined.

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Work, Done by a Constant Force

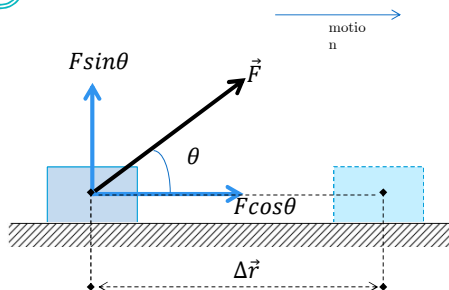
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The work, W , done on a system is the product of the magnitude of the force $|\vec{F}|$, the magnitude of the displacement $|\Delta\vec{r}|$ and $\cos\theta$:

$$W = |\vec{F}| |\Delta\vec{r}| \cos\theta$$

$$W = \vec{F} \cdot \Delta\vec{r}$$

where θ is the angle between the force and the displacement vectors.



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Work, Done by a Constant Force

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- Work is a scalar quantity could be: positive, negative or zero.
- The SI units of work is a Joule (J)

$$1 \text{ J} = 1 \text{ N} \cdot \text{m} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^2$$

- The meaning of the term work is distinctly different in physics than in everyday meaning.

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Work , Done by a Constant Force

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$$\text{Work is } \begin{cases} +ve ; \text{ when } 0^\circ \leq \theta < 90^\circ ; \text{ energy is transferred to the system} \\ -ve ; \text{ when } 90^\circ < \theta \leq 180^\circ ; \text{ energy is transferred from the system} \\ \text{Zero when } \begin{cases} \theta = 90^\circ \\ \Delta r = 0 \end{cases} ; \text{ energy of the system is constant} \end{cases}$$

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Work , Done by a Constant Force

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- Work is positive when projection of $\vec{F}$ onto $\Delta\vec{r}$ is in the same direction as the displacement.
- Work is negative when projection of $\vec{F}$ onto $\Delta\vec{r}$ is in the opposite direction as the displacement.
- A force does no work ($W = 0$) on the object if the force does not move through a displacement.
- The work done by a force on a moving object is zero when the force applied is perpendicular to the displacement of its point of application.

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Work, Done by a Constant Force

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- If the work done on the system is positive, energy is transferred to the system.
- If the work done on the system is negative, energy is transferred from the system.

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Work Done by a Varying Force

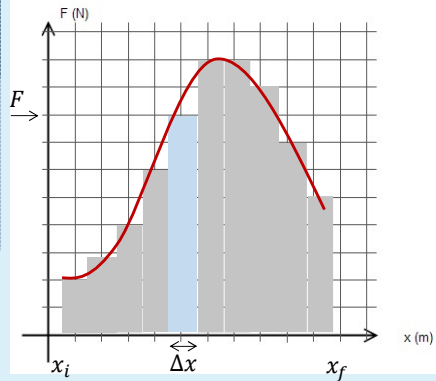
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- To use

$$W = |\vec{F}| |\Delta\vec{r}| \cos\theta$$

- The force must be constant.
- Assume that during a very small displacement, Δx , F is constant.
- For that displacement, $W \cong F\Delta x$
- For all of the intervals,

$$W \cong \sum_{x_i}^{x_f} F_x \Delta x$$



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Work Done by a Varying Force, cont.

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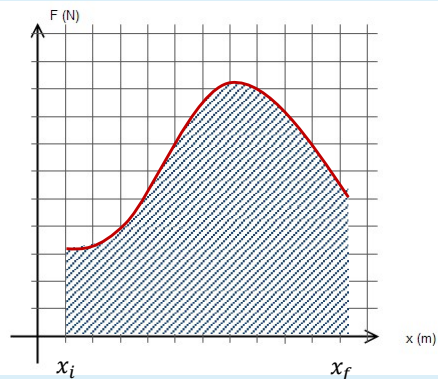
- Let the size of the small displacements approach zero.

$$W = \lim_{\Delta x \rightarrow 0} \sum_{x_i}^{x_f} F_x \Delta x$$

Therefore,

$$W = \int_{x_i}^{x_f} F_x dx$$

W
= the area under the curve
between x_i and x_f .



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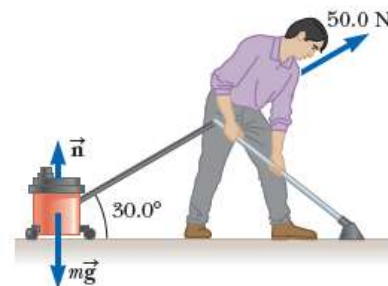
Work-Constant Force

Friday, 29 January, 2021 21:35

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.

A man cleaning a floor pulls a vacuum cleaner with a force of magnitude $F = 50\text{ N}$ at an angle of 30° with the horizontal. Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced (3 m) to the right.



Solution

Use the definition of work

$$W = F\Delta r \cos \theta = (50.0\text{ N})(3.00\text{ m})(\cos 30.0^\circ) = 130\text{ J}$$

Notice in this situation that the normal force $\vec{n}$ and the gravitational $\vec{F}_g = m\vec{g}$ do no work on the vacuum cleaner because these forces are perpendicular to its displacement.

Work-Constant Force-unit vectors

Saturday, 30 January, 2021 15:08

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.
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A particle moving in the xy plane undergoes a displacement given by $\Delta\vec{r} = (2\hat{i} + 3\hat{j})\text{ m}$ as a constant force $\vec{F} = (5\hat{i} + 2\hat{j})\text{ N}$ acts on the particle. Calculate the work done by $\vec{F}$ on the particle.

Solution

$$\begin{aligned}W &= \vec{F} \cdot \Delta\vec{r} = [5.0\hat{i} + 2.0\hat{j}\text{N}] \cdot [2.0\hat{i} + 3.0\hat{j}\text{m}] \\&= (5.0\hat{i} \cdot 2.0\hat{i}) + (5.0\hat{i} \cdot 3.0\hat{j}) + (2.0\hat{j} \cdot 2.0\hat{i}) + (2.0\hat{j} \cdot 3.0\hat{j}) \\&= 10 + 0 + 0 + 6 = 16\text{J}\end{aligned}$$

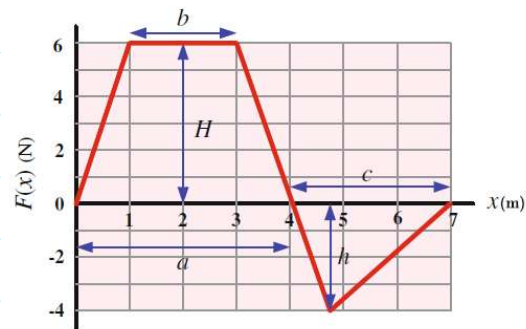
Work-Varying Force-Area

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A force acting on a particle varies with x as shown. Calculate the work done by the force on the particle as it moves from $x = 1\text{ m}$ to $x = 7\text{ m}$.



Solution

The work done by the force is equal to the area under the curve from $x = 1\text{ m}$ to $x = 7\text{ m}$. This area is equal to the area of the rectangular section from $x = 1\text{ m}$ to $x = 3\text{ m}$ plus the area of the triangular section from $x = 3\text{ m}$ to $x = 4\text{ m}$ plus the area of the triangular section from $x = 4\text{ m}$ to $x = 7\text{ m}$.

Evaluate the area of the rectangle:

$$W_{1 \rightarrow 3} = 6 \times 2 = 12\text{ J}$$

Evaluate the area of the first triangle:

$$W_{3 \rightarrow 4} = \frac{1}{2} \times 1 \times 6 = 3\text{ J}$$

Evaluate the area of the second triangle:

$$W_{4 \rightarrow 7} = \frac{1}{2} \times 3 \times -4 = -6\text{ J}$$

Find the total work done by the force on the particle:

$$W_{1 \rightarrow 7} = W_{1 \rightarrow 3} + W_{3 \rightarrow 4} + W_{4 \rightarrow 7} = 12 + 3 - 6 = 9\text{ J}$$

Work-Varying Force-Integration

Saturday, 30 January, 2021 15:08

Force $\vec{F} = (3x^2\hat{i} + 4\hat{j}) N$ with x in meters, acts on a particle, changing only the kinetic energy of the particle. How much work is done on the particle as it moves from coordinates (2 m, 3 m) to (3 m, 0m)?

Solution

The force is a variable force because its x component depends on the value of x. Thus, we must use

$$W = \int_{x_i}^{x_f} F(x) dx$$

We set up two integrals, one along each axis:

$$\begin{aligned} W &= \int_2^3 3x^2 dx + \int_3^0 4 dy = 3 \int_2^3 x^2 dx + 4 \int_3^0 dy \\ &= 3 \left[\frac{1}{3} x^3 \right]_2^3 + 4[y]_3^0 = [3^3 - 2^3] + 4[0 - 3] = 7.0J \end{aligned}$$

The positive result means that energy is transferred to the particle by force $\vec{F}$. Thus, the kinetic energy of the particle increases and, because $K = \frac{1}{2}mv^2$, its speed must also increase. If the work had come out negative, the kinetic energy and speed would have decreased.

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