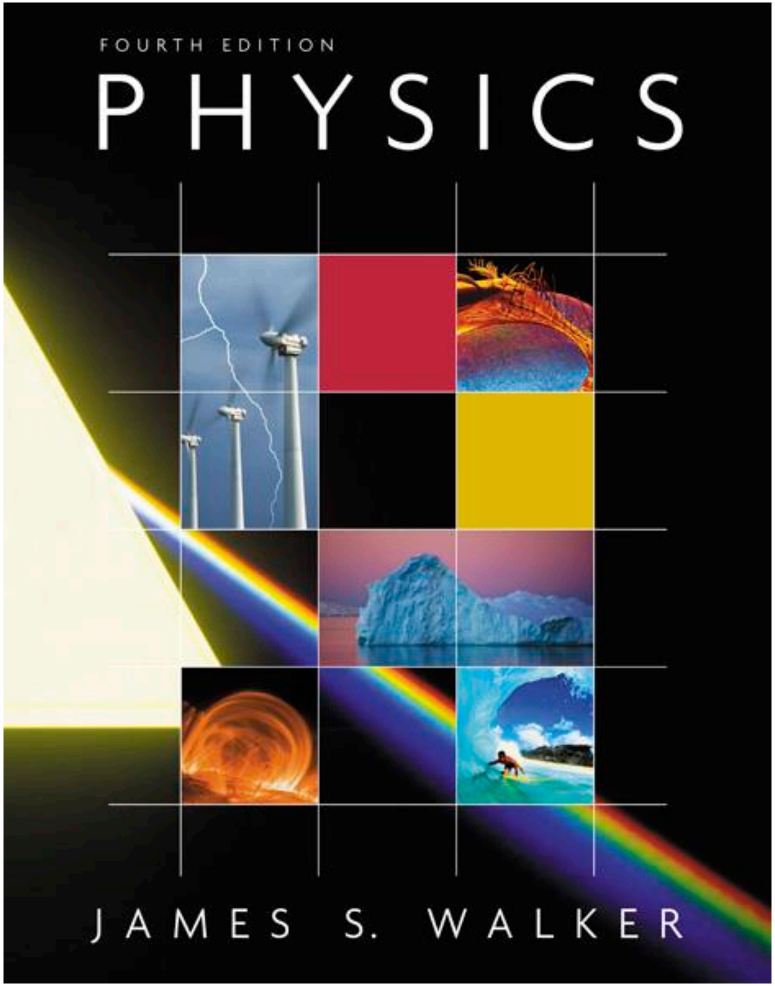


Lecture Outline

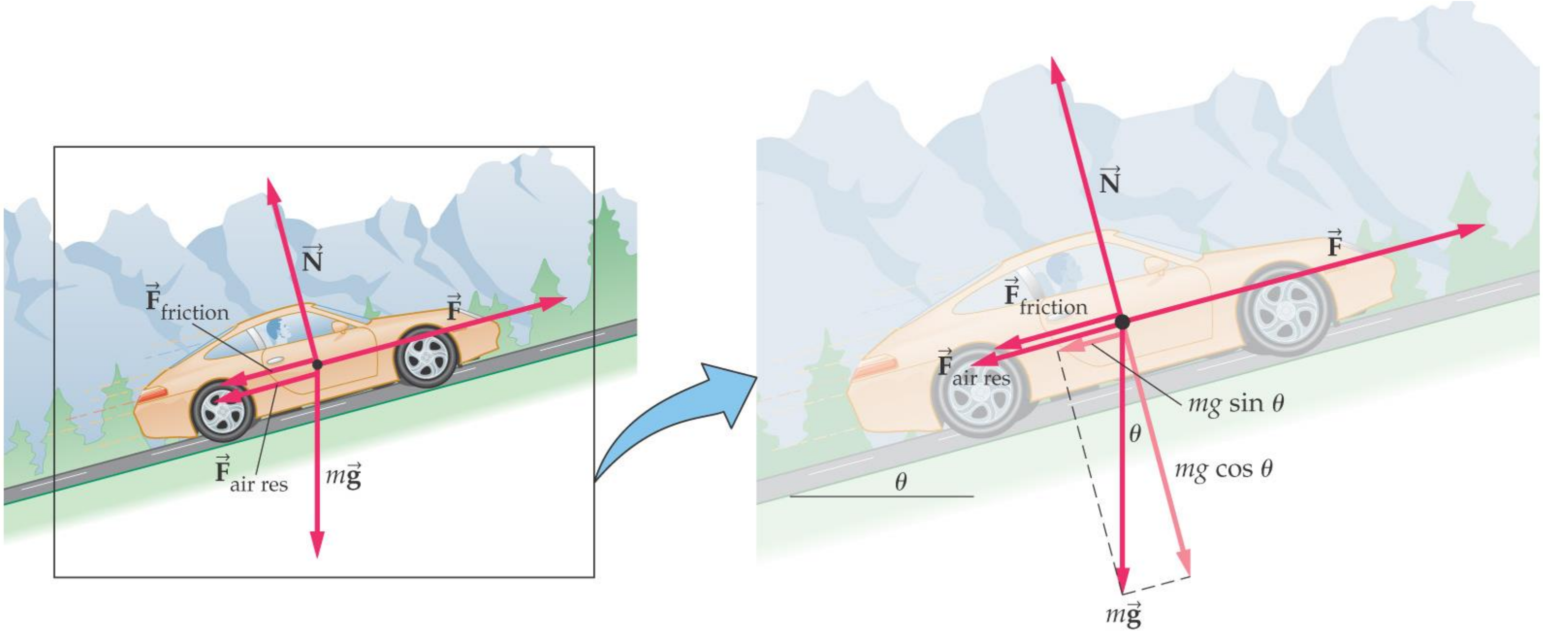
Chapter 7

Physics, 4th Edition

James S. Walker

Chapter 7

Work and Kinetic Energy



Units of Chapter 7

- Work Done by a Constant Force
- Kinetic Energy and the Work-Energy Theorem
- Work done by a variable forces
- Power

7-1 -Work Done by a Constant Force

The definition of work, when the force is parallel to the displacement:

$$W = Fd \qquad (7\text{-}1)$$

Work is a scalar quantity

SI unit: Newton-meter (N·m) = joule, J

1 Joule = 1 Newton * 1 meter

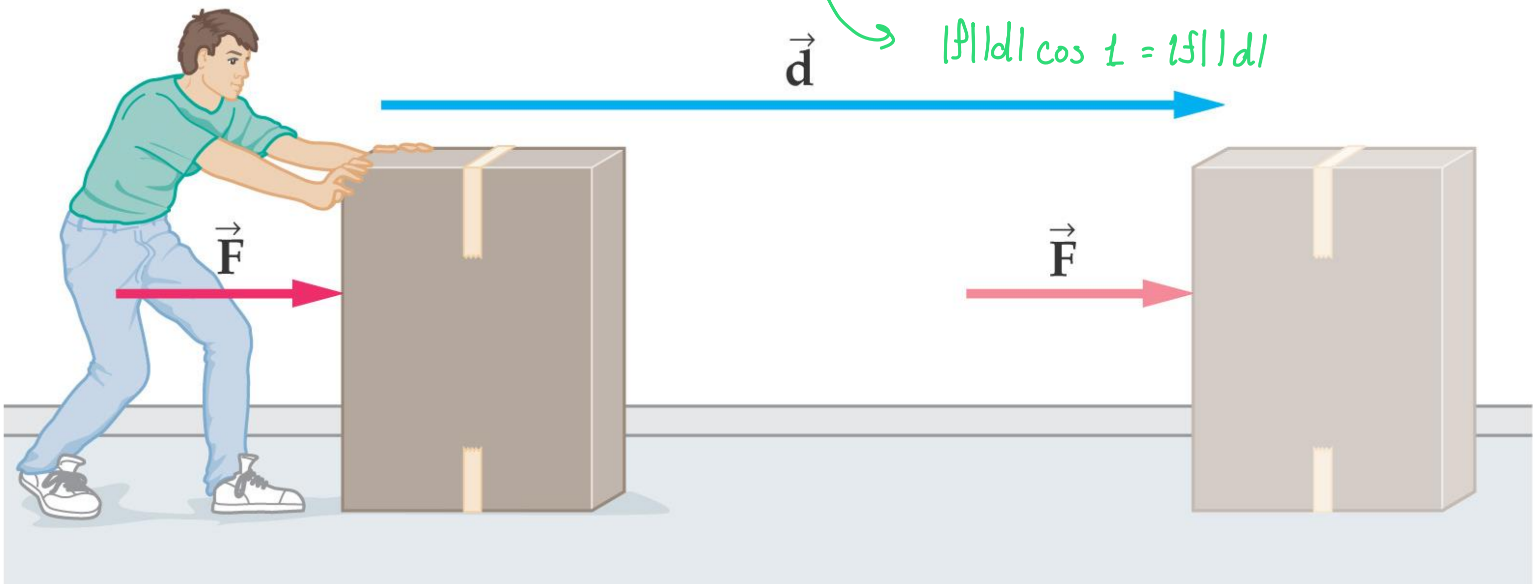
1 J = 1 N * m

$F \cdot d = |f|\,|d| \cos\theta$

(J) or N.M

when $\theta = 0$, then force & displacement are parrallel

$|f||d| \cos 1 = |f||d|$



when $\theta = 0$ f & d are parrallel

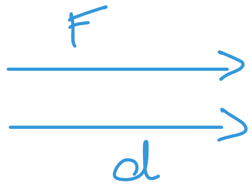
then : $|f||d| \cos(0) = |f|\,|d| \times 1$

$w = |f|\,|d|$

Example:-7-1

- An intern pushes a 72kg patient on a 15kg gurney, producing an acceleration of 0.60m/s2.
- A) How much work does the intern do by pushing the patient and gurney through a distance of 2.5m?Assume the gurney moves without friction.- W=130J
- B)How far must the intern push the gurney to do 140J of work? d= 2.7m
- EXERCISE:7-1 (Assignment)

Example:-7-1



both are parrallel, so we use

$w = f\,d$

① $w = ?$

1- find $f = ma \rightarrow (72+15)\,0.6 = 52.2\,N$

2- $w = (52.2)(2.5) = 130.5\,J$

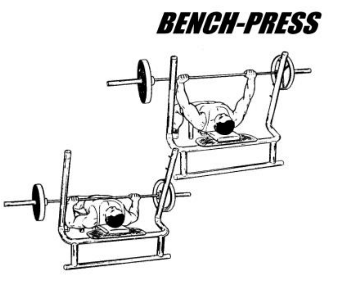
② $w = 140$, $f = 52.2\,N$, $d = ?$

$d = \frac{w}{f} = \frac{140}{52.2} = 2.7\,m$

Calculate Work

- During the ascent phase of a rep of the bench press, the lifter exerts an *average* vertical force of 1000 N against a barbell while the barbell moves 0.8 m upward
- How much work did the lifter do to the barbell? Work = Fd = 1000*0.8=800J

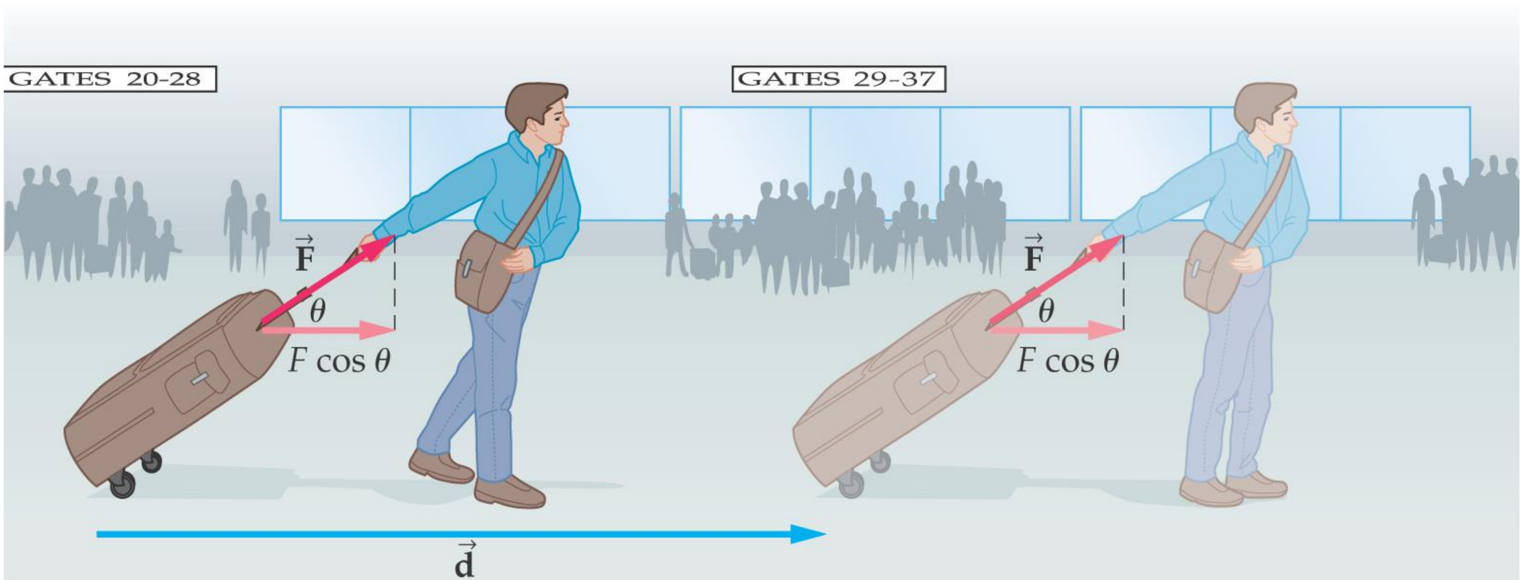
d ↑ ↑ F so → $w = Fd$

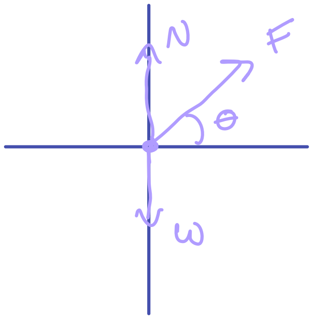


7-1 --Work Done by a Constant Force

If the force is at an angle to the displacement: WORK = Fxd=

$$W = (F\cos\theta)d = Fd\cos\theta \qquad (7\text{-}3)$$





$\Sigma f_x = 0 + 0 + f\cos\theta = ma_x$

$f\cos\theta = ma_x$

$\Sigma f_y = N - w + f\sin\theta = 0$

displacment is parallel to x, so work is happening on x

$\Rightarrow \quad w = fd$

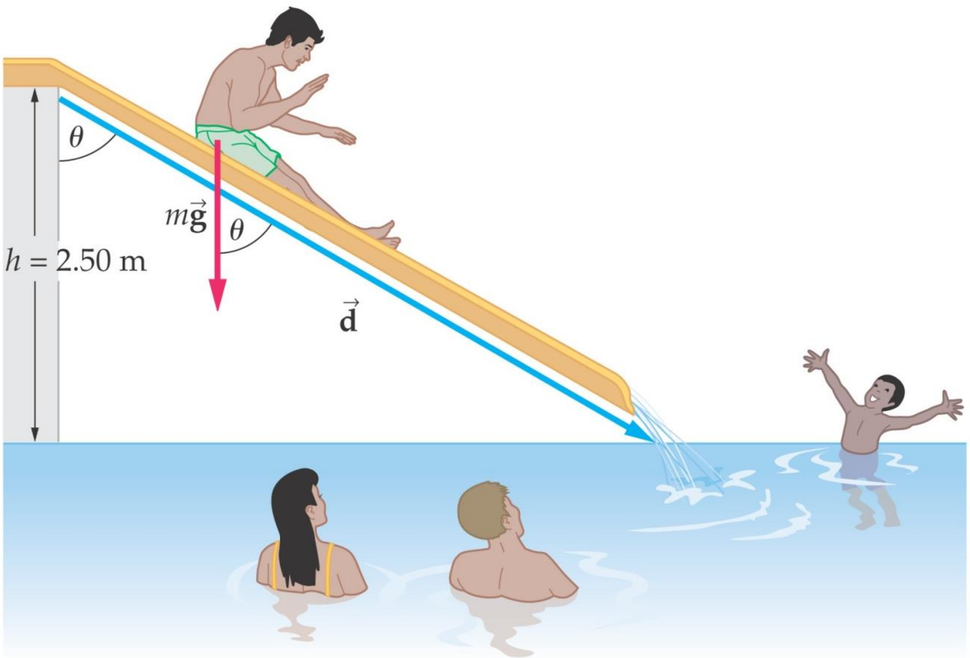
$w = f_x d$

$w = f\cos\theta \, d$

7-1 --Work Done by a Constant Force

The work can also be written as the dot product of the force and the displacement:

$$W = \vec{\mathbf{F}} \cdot \vec{\mathbf{d}} = Fd\cos\theta$$



* we need to find which force is needed

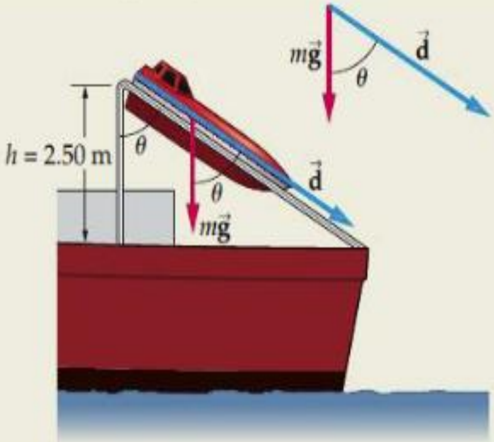
→ gp

EXAMPLE 7–2 GRAVITY ESCAPE SYSTEM

REAL-WORLD PHYSICS In a gravity escape system (GES), an enclosed lifeboat on a large ship is deployed by letting it slide down a ramp and then continuing in free fall to the water below. Suppose a 4970-kg lifeboat slides a distance of 5.00 m on a ramp, dropping through a vertical height of 2.50 m. How much work does gravity do on the boat?

PICTURE THE PROBLEM

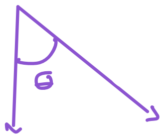
From our sketch, we see that the force of gravity $m\vec{g}$ and the displacement $\vec{d}$ are at an angle θ relative to one another when placed tail-to-tail, and that θ is also the angle the ramp makes with the vertical. In addition, we note that the vertical height of the ramp is $h = 2.50$ m and the length of the ramp is $d = 5.00$ m.



STRATEGY

By definition, the work done on the lifeboat by gravity is $W = Fd\cos\theta$, where $F = mg$, $d = 5.00$ m, and θ is the angle between $m\vec{g}$ and $\vec{d}$. We are not given θ in the problem statement, but from the right triangle that forms the ramp we see that $\cos\theta = h/d$. Once θ is determined from the geometry of our sketch, it is straightforward to calculate W.

EXAMPLE 7–2 GRAVITY ESCAPE SYSTEM



→ f & d are not parrallel there is an angle between them, so $fd\cos\theta$

work = $mg\,d\cos\theta$

$mgd\ \frac{adj}{hyp}$

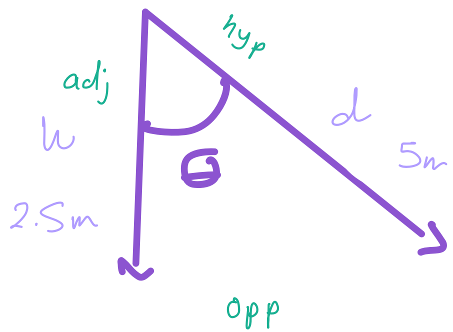
$mg\cancel{d} \times \frac{h}{\cancel{d}}$

$mg \times h$

$4970 \times 9.81 \times 2.5 = 121\,889.25\ J$

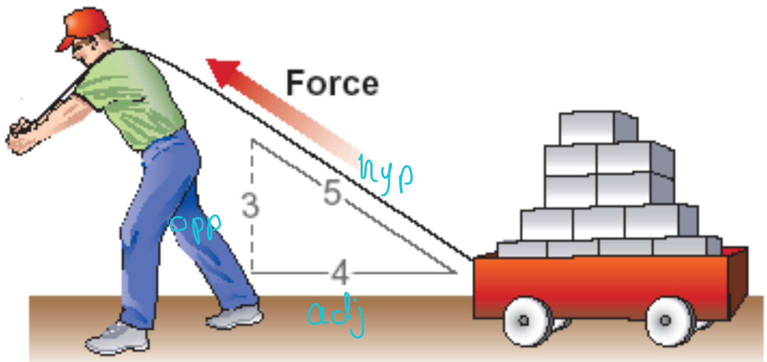
→ $122 \times 10^3\ J$

or $122\ KJ$

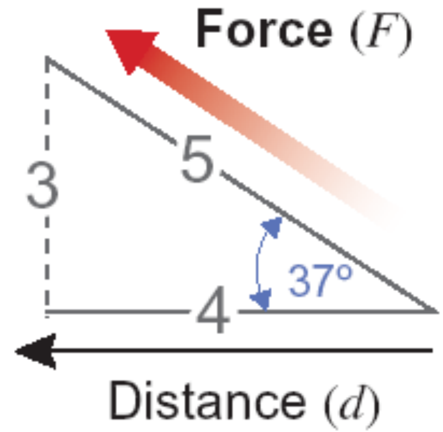


Force at an Angle to the Distance

PROBLEM



ANALYSIS



$Fd \cos \theta$

$Fd \times \frac{adj}{hyp}$

$Fd \times \frac{d}{F}$

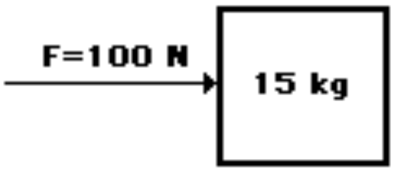
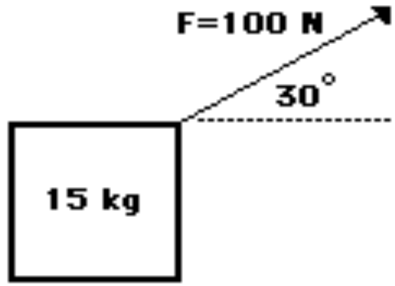
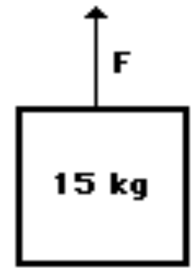
SOLUTION

$$W = Fd \times \left(\frac{4}{5}\right) = Fd \cos 37^{\circ}$$

Fd cos (theta)=5*4 (4/5)= 15.97=16J

= 5*4 COS 37= 15.97J=16J

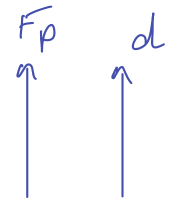
Work Calculations

Diagram A	Diagram B	Diagram C
		
A 100 N force is applied to move a 15 kg object a horizontal distance of 5 meters at constant speed. Parraller	A 100 N force is applied at an angle of 30º to the horizontal to move a 15 kg object at a constant speed for a horizontal distance of 5 m. angle between them	An upward force is applied to lift a 15 kg object to a height of 5 meters at constant speed.

W= F x d	W=F x d cos 30^0	W = mgd
=100 x 5	100 x 5 x .87	= 15 x 9.8 x 5
=500 J	= 433 J	= 735 J

Specail case :

Calculate the work done by a person: $w = fd$

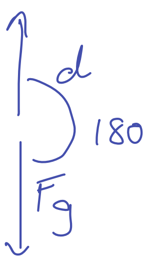


$w = f_p d$

$w = mgd$

$\theta = 0$

Calculate the work done by gravity:



$\rightarrow$

$w = f_g d \cos\theta$

$w = f_g d \cos 180$

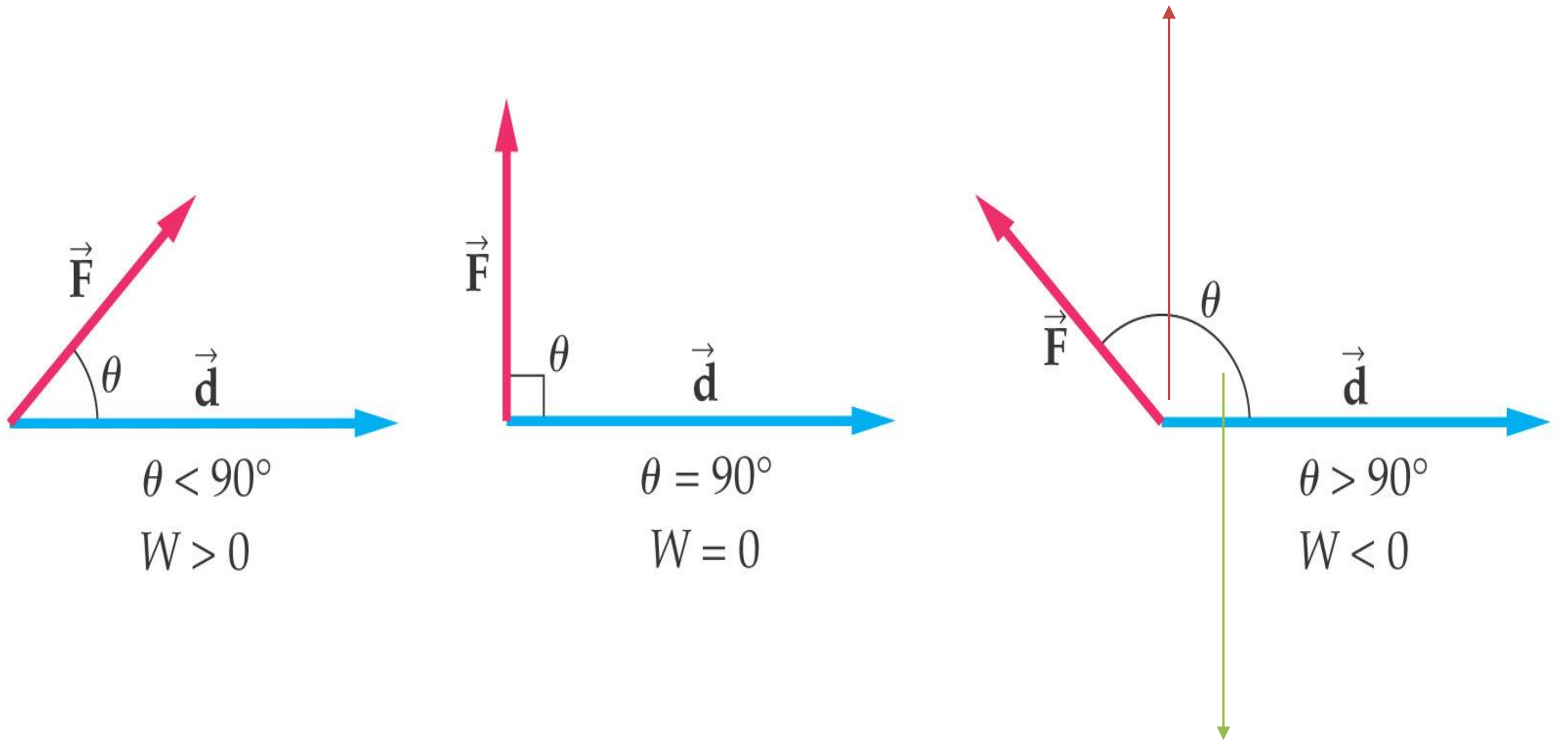
$w = f_g d \cos(-1)$

$\theta = 180$

$w = -mgd$

7-1 --Work Done by a Constant Force

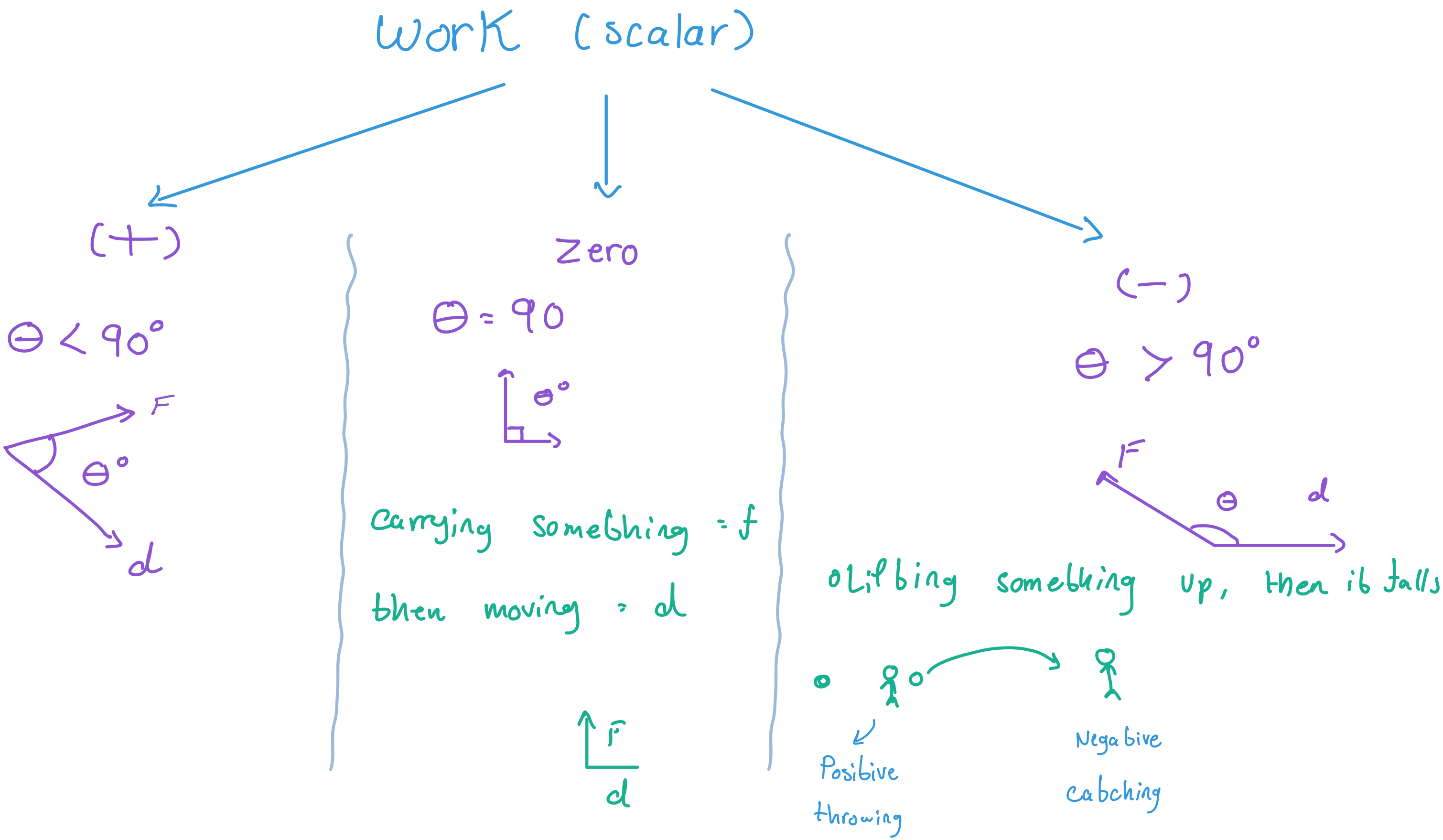
The work done may be **positive, zero, or negative,** depending on the angle between the force and the displacement:



- & + Work

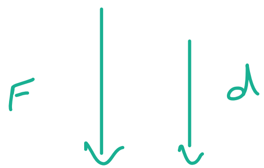
- Positive work is performed when the direction of the force and the direction of motion are the same
  - ascent phase of the bench press
  - Throwing a ball
  - push off (upward) phase of a jump

- & + Work


Work (scalar)
(+)
θ < 90°
F
θ°
d
Zero
θ = 90
θ°
Carrying something = f
then moving = d
F
d
(−)
θ > 90°
F
θ
d
Lifting something up, then it falls
Positive
throwing
Negative
catching

Calculate Work

- During the *descent* phase of a rep of the bench press, the lifter exerts an *average* vertical force of 1000 N against a barbell while the barbell moves 0.8 m *downward*



$W = 1000 \times 0.8 = -800$ J

Calculate Work

Table of Variables

Force = +1000 N

Displacement = -0.8 m

- Force is positive due to pushing upward
- Displacement is negative due to movement downward

Calculate Work

Table of Variables

Force = +1000 N

Displacement = -0.8 m

Select the equation and solve:

$$Work = Force \times displacement$$

$$Work = \left(+1000N\right) \times \left(-0.8m\right)$$

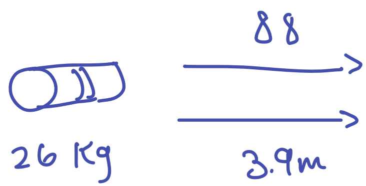
$$Work = \underline{-800}\,Nm \Rightarrow -800\,Joule \Rightarrow -800J$$

- & + Work

- Positive work
- Negative work is performed when the direction of the force and the direction of motion are the *opposite*
  - descent phase of the bench press
  - catching
  - landing phase of a jump

Problem 4: A farmhand pushes a 26 kg bale of hay 3.9 m across the floor of a barn. If she exerts a horizontal force of 88 N on the bay, how much work has she done? (Answer 343.2)

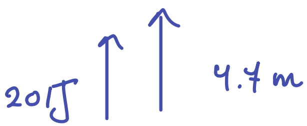
Work = Fd= 88*3.9=343.2J



parrallel = $w = f d$

$w = 88 \times 3.9 = 343.2 J$

Problem 5: Children in a tree house lift a small dog in a basket 4.7 m up to their house. If it takes 201 J of work to do this, what is the combined mass of the dog and basket? (Ans. 4. 36 kg) Work = mgd m=Work/gd= 201/(9.81*4.7)= 4.359kg



$m = ?$

$$work = mgd$$

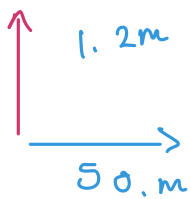
$$m = \frac{work}{gd}$$

$$m = \frac{201}{(9.81)(4.7)} = 4.36\ Kg$$

Problem 6: Early one October, you go to a pumpkin patch to select your Halloween pumpkin. You lift the 3.2 kg pumpkin to a height of 1.2 m, then carry it 50.0 m (on level ground) to check-out stand. (a) Calculate the work you do on the pumpkin as you lift it from the ground. (b) How much work do you do on the pumpkin as you carry it from the field?

(Ans. 37.4 Work = mgd=3.2*9.81*1.2=37.7J

Work = Fd cos theta= zero



Find two works
lifting
+ moving

a) $w = mgd$

$= 3.2(9.81)1.2$

$w = 37.4 J$

b) $fd \cos \theta$

$fd \cos 90$

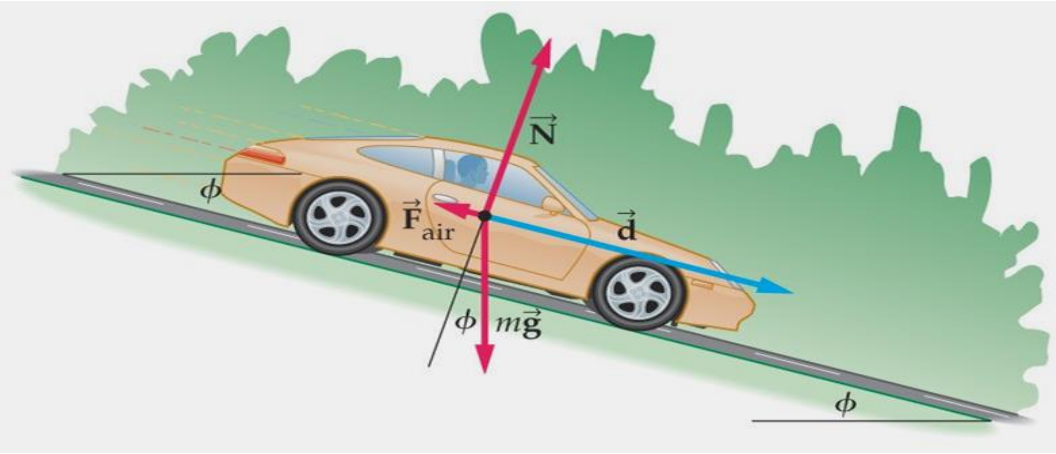
$w = 0$

7-1-- Work Done by a Constant Force

If there is more than one force acting on an object, we can find the work done by each force, and also the work done by the net force:

$$W_{\text{total}} = (F_{\text{total}} \cos\theta)d = F_{\text{total}} d \cos\theta \qquad (7\text{-}5)$$

Work is a scalar quantity



Example 7-3

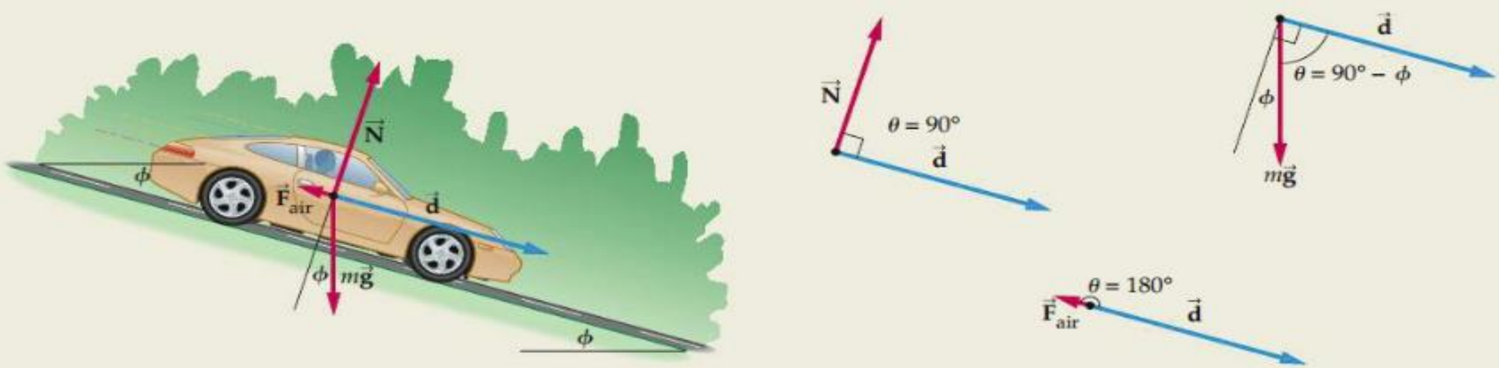
A car of mass 1550 kg coasts down a hill at an angle of 5.0º below the horizontal. The car is acted on by three forces : (i) the normal force **N** exerted by the road, (ii) a force due to air resistance , $F_{air,}$ and (iii) the force of gravity,mg. Find the work done by each of the forces and the total work done on the car as it travels a distance 20.4 m down the hill. The force due to air resistance is 15.0 N.

EXAMPLE 7–3 A COASTING CAR I

A car of mass m coasts down a hill inclined at an angle ϕ below the horizontal. The car is acted on by three forces: (i) the normal force $\vec{\mathbf{N}}$ exerted by the road, (ii) a force due to air resistance, $\vec{\mathbf{F}}_{air}$, and (iii) the force of gravity, $m\vec{\mathbf{g}}$. Find the total work done on the car as it travels a distance d along the road.

PICTURE THE PROBLEM

Because ϕ is the angle the slope makes with the horizontal, it is also the angle between $m\vec{\mathbf{g}}$ and the downward normal direction, as was shown in Figure 5–15. It follows that the angle between $m\vec{\mathbf{g}}$ and the displacement $\vec{\mathbf{d}}$ is $\theta = 90° - \phi$. Our sketch also shows that the angle between $\vec{\mathbf{N}}$ and $\vec{\mathbf{d}}$ is $\theta = 90°$, and the angle between $\vec{\mathbf{F}}_{air}$ and $\vec{\mathbf{d}}$ is $\theta = 180°$.



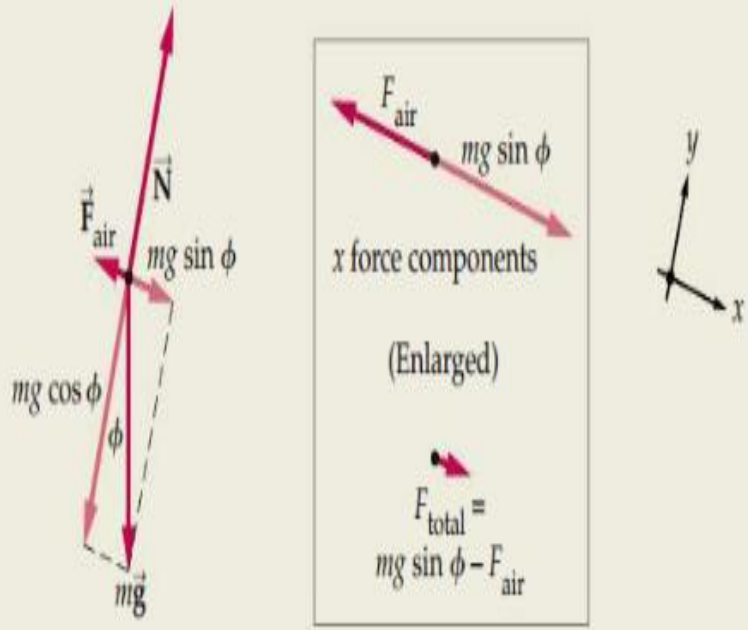
STRATEGY

For each force we calculate the work using $W = Fd\cos\theta$, where θ is the angle between that particular force and the displacement $\vec{\mathbf{d}}$. The total work is the sum of the work done by each of the three forces.

Consider the car described in Example 7–3. Calculate the total work done on the car using $W_{total} = F_{total}d\cos\theta$.

PICTURE THE PROBLEM

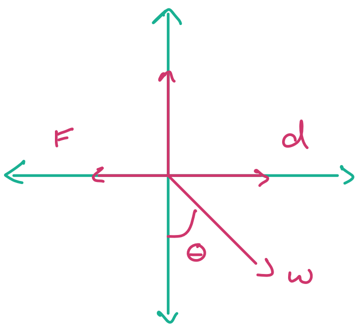
First, we choose the x axis to point down the slope, and the y axis to be at right angles to the slope. With this choice, there is no acceleration in the y direction, which means that the total force in that direction must be zero. As a result, the total force acting on the car is in the x direction. The magnitude of the total force is $mg\sin\phi - F_{air}$, as can be seen in our sketch.



STRATEGY

We begin by finding the x component of each force vector and then summing them to find the total force acting on the car. As can be seen from the figure, the total force points in the positive x direction; that is, in the same direction as the displacement. Therefore, the angle θ in $W = F_{total}d\cos\theta$ is zero.

Example 7-3

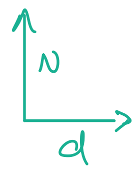


work = $f d \cos\theta$

① work N

= $N d \cos 90$

= zero



② work fair

= $f d \cos 180$

= $15(20.4) \cos 180$

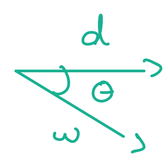
= -306 J

③ work g

= $mgd \cos 85$?

= $1550(9.81) \cos 85$

= 27035 J

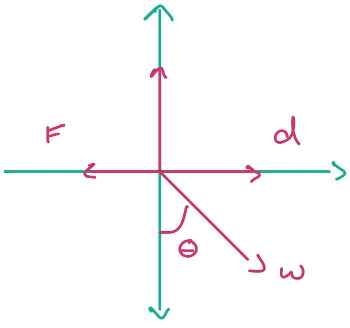


ΣW :

= zero − 306 + 27035

= 26729 J

Example 7-3



$\Sigma F_x = w\sin\theta - f_{fair}$

$\Sigma F_y = N - w\cos\theta$

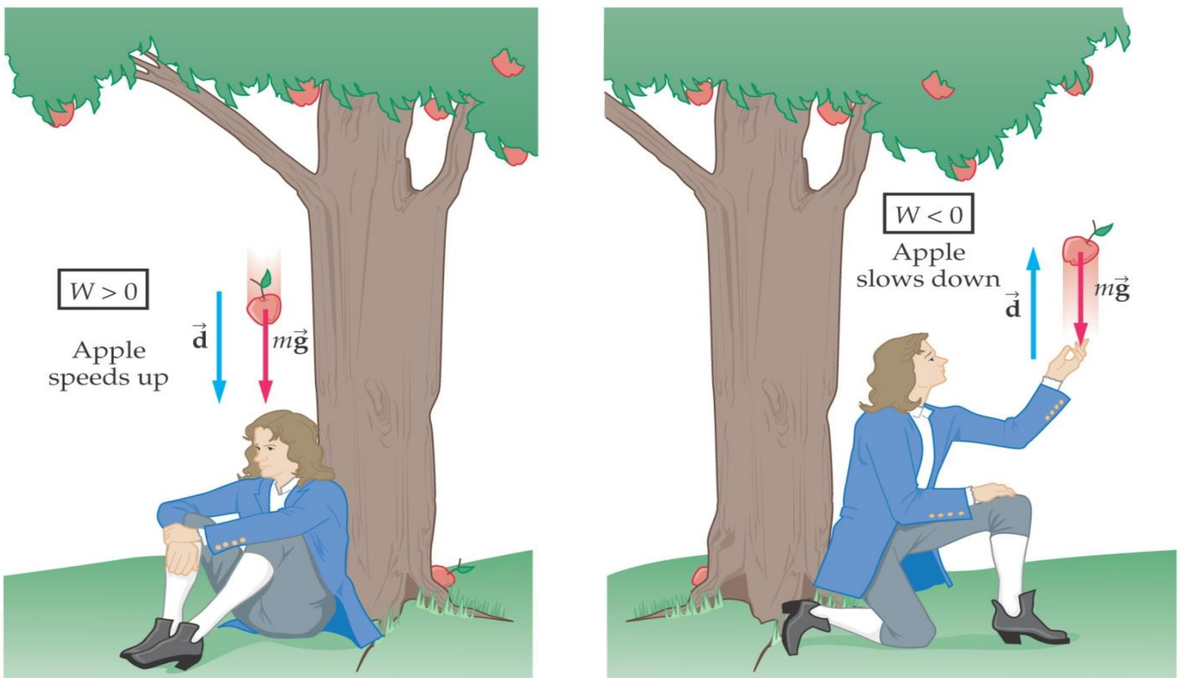
$= w\sin\theta - f_{air}$ because x is parallel to d

7-2 --Kinetic Energy and the Work-Energy Theorem

Absent

When positive work is done on an object, its speed increases; when negative work is done, its speed decreases.

$v_f^2 = v_i^2 + 2a\Delta y$



7-2-- Kinetic Energy and the Work-Energy Theorem

After algebraic manipulations of the equations of motion, we find:

$$W_{\text{total}} = \frac{1}{2}mv_{\text{f}}^2 - \frac{1}{2}mv_{\text{i}}^2$$

Therefore, we define the kinetic energy:

$$K = \frac{1}{2}mv^2 \qquad \text{(7-6)}$$

7-2-- Kinetic Energy and the Work-Energy Theorem

Work-Energy Theorem: The total work done on an object is equal to its change in kinetic energy.

$$W_{\text{total}} = \Delta K = \frac{1}{2}m{v_{\text{f}}}^2 - \frac{1}{2}m{v_{\text{i}}}^2 \qquad (7\text{-}7)$$

Exercises:-

Exercise:- 7-6

A boy exerts a force of 11.0N above the horizontal at 29° on a 6.40Kg sled. Find

(a) the work done by a boy and

(b) the final speed of the sled after it moves 2.00m, assuming the sled starts with an initial speed of 0.500mls and slides horizontally without friction.

W = 19.2J

$V_f =$ 2.50m/s

Exercise:- 7-2

A truck moving at 15m/s has a kinetic energy of 4.2 x 10 5 J.

a) What is the mass of the truck? m= 3733 Kg
b) By what multiplicative factor does the kinetic energy of a truck increases if its speed is doubled
c) K.E increases by four

Exercise 7-3:-How much work is required for 74- Kg sprinter to accelerate from rest to 2.2m/s?------W = 180J

- A car with a mass of 1,300 kg is going straight ahead at a speed of 30 m/sec (67 mph). The brakes can supply a force of 9,500 N.
- Calculate:

  a) The kinetic energy of the car. (585000 J)

  b) The distance it takes to stop. (61.58 m)

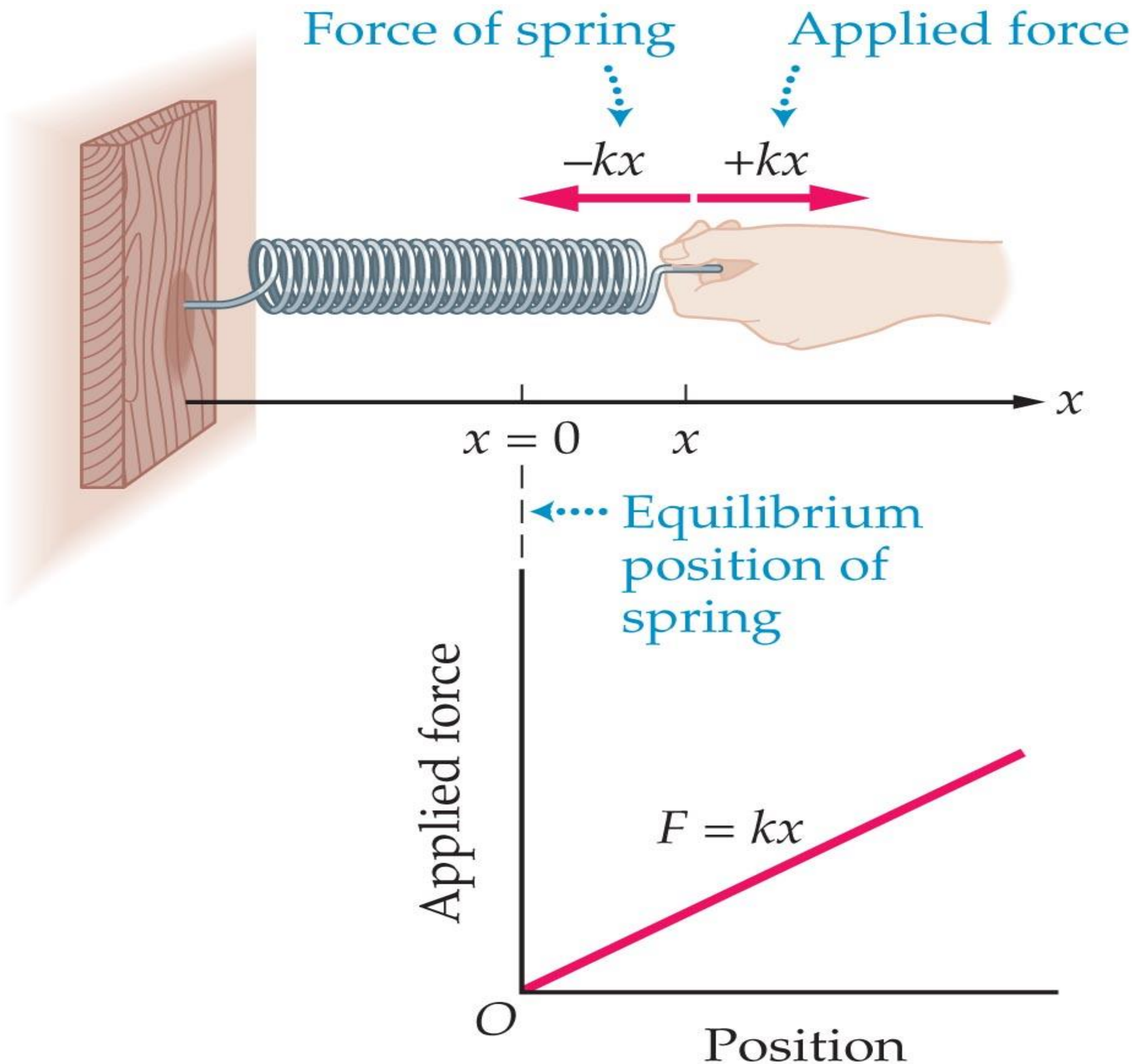
H.W

Problems

Problem 19: How much work is needed for a 73 kg runner to accelerate from rest to 7.7 m/s? (2164.08 J)

Problem 21: A 9.5 g bullet has a speed of 1.3 km/s. (a) What is its kinetic energy in Joules? (b) What is the bullet's kinetic energy if its speed is halved? (c) If its speed is doubled? (8027.5 J, 2006.87 J, 32110 J)

absen


Force of spring
Applied force
−kx
+kx
x
x = 0
x
Equilibrium position of spring
Applied force
F = kx
O
Position

work = $fd\cos\theta$

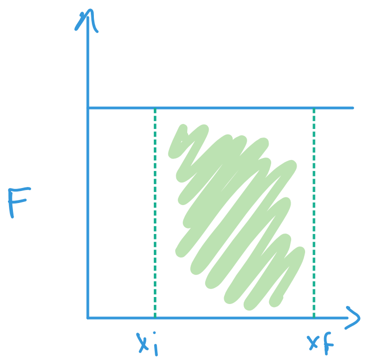
equations

fd

mgd

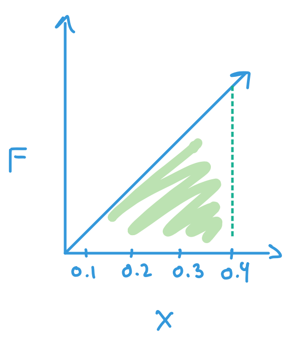
$\Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

$W = \frac{1}{2}kx^2$



area ☐ = length x width

work = d x f



area Δ = $\frac{1}{2}$ (base) (length)

$\frac{1}{2}(x)(F_{spring})$

$\frac{1}{2}(x)(kx)$

$\frac{1}{2}kx^2$

7-3 Work Done by a Variable Force

The force needed to stretch a spring an amount x is $F = kx$.

Therefore, the work done in stretching the spring is

$$W = \frac{1}{2}kx^2 \qquad (7\text{-}8)$$

- Exercise 4
- The spring in a pinball launcher has a force constant of 405 N/m. How Much work is required to compress the spring a distance of 3.00 cm?

$K = 405\ N/m$

$X = 3.00cm \rightarrow 3 \times 10^{-2} m$

$w = ?$

① $w = \frac{1}{2} K x^2$

$\frac{1}{2}(405)(-3 \times 10^{-2})^2 = 0.18\ J$

why? because it is compressed.

7-4 ---Power

Power is a measure of the rate at which work is done:

$$P = \frac{W}{t} \qquad (7\text{-}10)$$

Power = $\frac{\text{work}}{\text{time}}$

$\frac{fd}{\text{time}} \rightarrow \frac{N \cdot m}{s}$

$fv \rightarrow N \cdot m/s$

$mav \rightarrow Kg \cdot m/s^2 \cdot m/s$

SI unit: J/s = watt, W

1 horsepower = 1 hp = 746 W

$\frac{1 hp}{746 w}$

Power is a scalar quantity

Power!

- Power is the rate that we use energy.
- Power = Work or Energy / Time
- $P = W/t = F \times d/t = F v$
- The units for power :
  - J/s
  - Kg m^2 / s^2 /s
  - N m / s

Power Calculation

- A 5 Kg Cart is pushed by a 30 N force against friction for a distance of 10m in 5 seconds. Determine the Power needed to move the cart.
- P = F x d / t
- P = 30 N (10 m) / 5 s
- P = 60 N m /s
- P = 60 watts

$m = 5$, $F = 30$, $x = 10$, $t = 5$

$$\text{power} = \frac{\text{work}}{\text{time}}$$

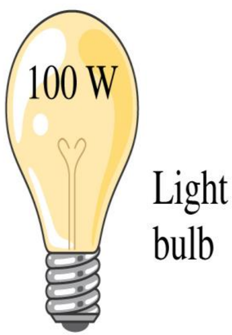
$$= \frac{fd}{\text{time}}$$

$$\frac{30 \times 10}{5} = 60 \text{ watt}$$

Work-Kinetic Energy Theorem

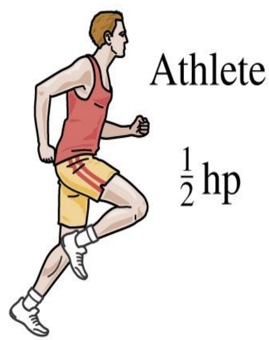
Power

Examples of power



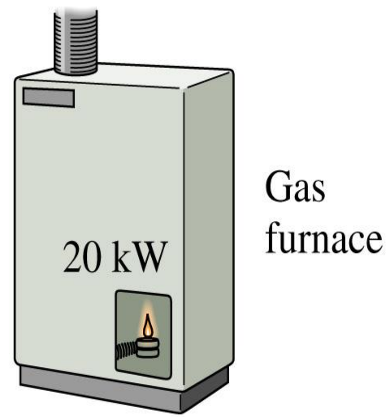
Electrical energy ⟶ light and heat at 100 J/s.

change from electrical to thermal.



Chemical energy of glucose and fat ⟶ mechanical energy at ≈350 J/s ≈ $\frac{1}{2}$ hp.

work → change from kinetic to thermal



Chemical energy of gas ⟶ thermal energy at 20,000 J/s.

7-4 --Power

If an object is moving at a constant speed in the face of friction, gravity, air resistance, and so forth, the power exerted by the driving force can be written:

$$P = \frac{Fd}{t} = F\left(\frac{d}{t}\right) = Fv \qquad \text{(7-13)}$$

Example:- 7-8

- To pass a slow moving truck, you want your fancy 1.30 x 10³ Kg car to accelerate from 13.4m/s to 17.9m/s in 3.00s.What is the minimum power required for this pass?
- Sol: $\Delta k = 9.16 \times 10^4$ J
- P = 3.05×10^4 watt

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{\Delta K}{\text{time}}$$

$$\frac{\frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2}{\text{time}}$$

$$\frac{\frac{1}{2} m (v_f^2 - v_i^2)}{\text{time}}$$

$$\frac{\frac{1}{2}(1.30 \times 10^3)(14.9^2 - 13.4^2)}{3.00}$$

$= 30514.5$ watt $\rightarrow 30 \times 10^4$ watt

Summary of Chapter 7

- If the force is constant and parallel to the displacement, work is force times distance

- If the force is not parallel to the displacement,

$$W = (F \cos \theta)d = Fd \cos \theta$$

- The total work is the work done by the net force:

$$W_{\text{total}} = (F_{\text{total}} \cos \theta)d = F_{\text{total}} d \cos \theta$$

Summary of Chapter 7

- SI unit of work: the joule, J
- Total work is equal to the change in kinetic energy:

$$W_{\text{total}} = \Delta K = \frac{1}{2}mv_{\text{f}}^2 - \frac{1}{2}mv_{\text{i}}^2$$

where

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

Summary of Chapter 7

- Work done by a spring force:

$$W = \frac{1}{2}kx^2$$

- Power is the rate at which work is done:

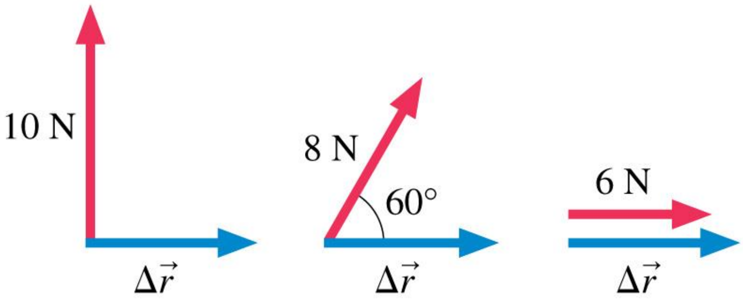
$$P = \frac{W}{t}$$

- SI unit of power: the watt, W

Class Question

Which force does the most work?

1. The 6 N force.
2. The 8 N force.
3. The 10 N force.
4. They all do the same amount of work.



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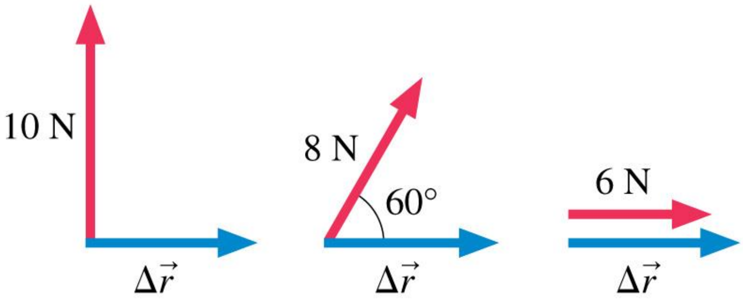
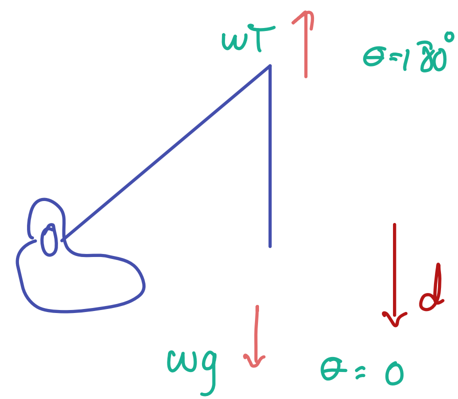


Class Question

A crane lowers a steel girder into place at a construction site. The girder moves with constant speed. Consider the work W_g done by gravity and the work W_T done by the tension in the cable. Which of the following is correct?

1. W_g is positive and W_T is positive.
2. W_g is negative and W_T is negative.
3. W_g is positive and W_T is negative.
4. W_g and W_T are both zero.
5. W_g is negative and W_T is positive.



WT → θ = 180 → −

mg → θ = 0 → +

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