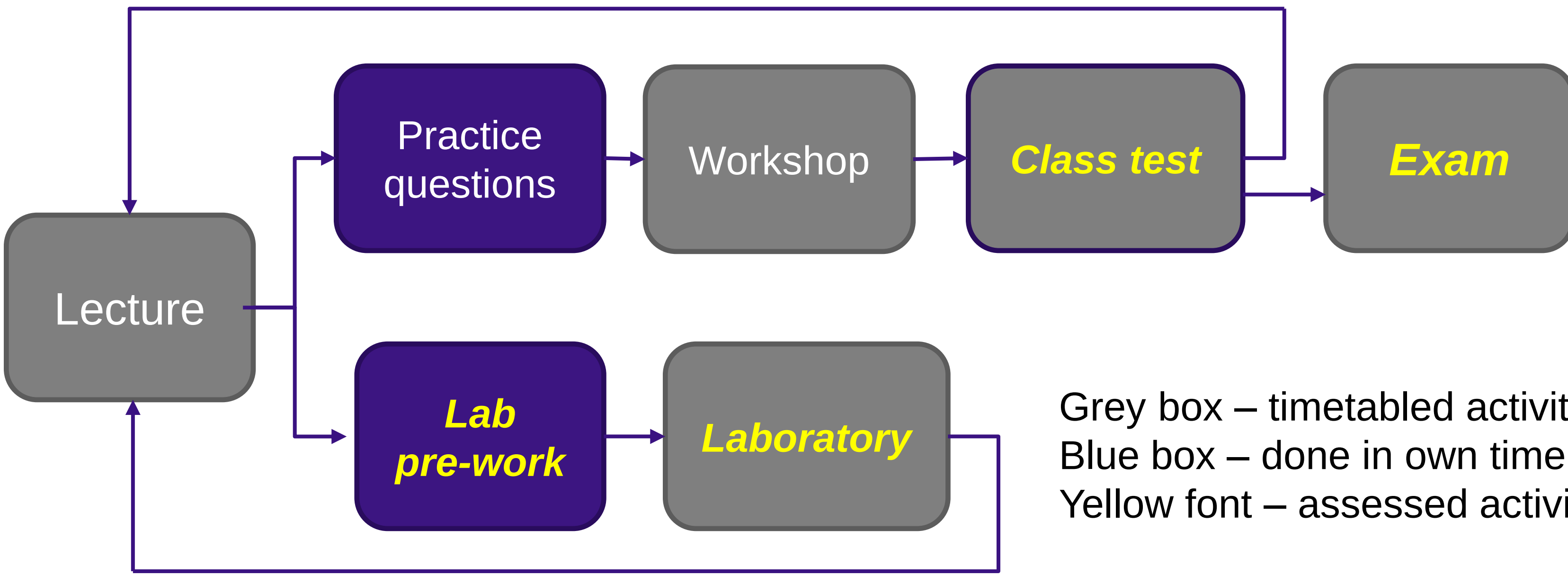
Lecture 3: Work and Energy

How you'll learn in this subject

- You'll be introduced to new concepts and principles with worked examples in lectures
- You'll practise applying these concepts and models in workshops
- You'll test the validity of some models in laboratory



Grey box – timetabled activity
Blue box – done in own time
Yellow font – assessed activity

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Roadmap for today

- Work
- Energy
  - ➢ Kinetic energy
  - ➢ Potential energy
  - ➢ Conservation of energy
- Power
- Q & A before class test

(With acknowledgments to Danica Solina)

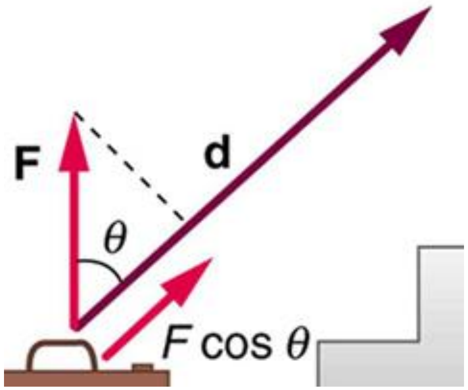
Work

Work is energy transferred, to or from, an object by means of a force acting on the object

- Work is a scalar quantity
- Can be positive or negative, depending on the direction of work on in the system
- When work is done, transformation of energy will also occur

These people are doing work as they push on the car as it moves.

Work (2)



- Work is a scalar product of the applied force and the displacement

- The work done by a constant force *F* acting over a displacement *s* is:

$$W = \vec{F}.\vec{s} = F\,s\cos\theta$$

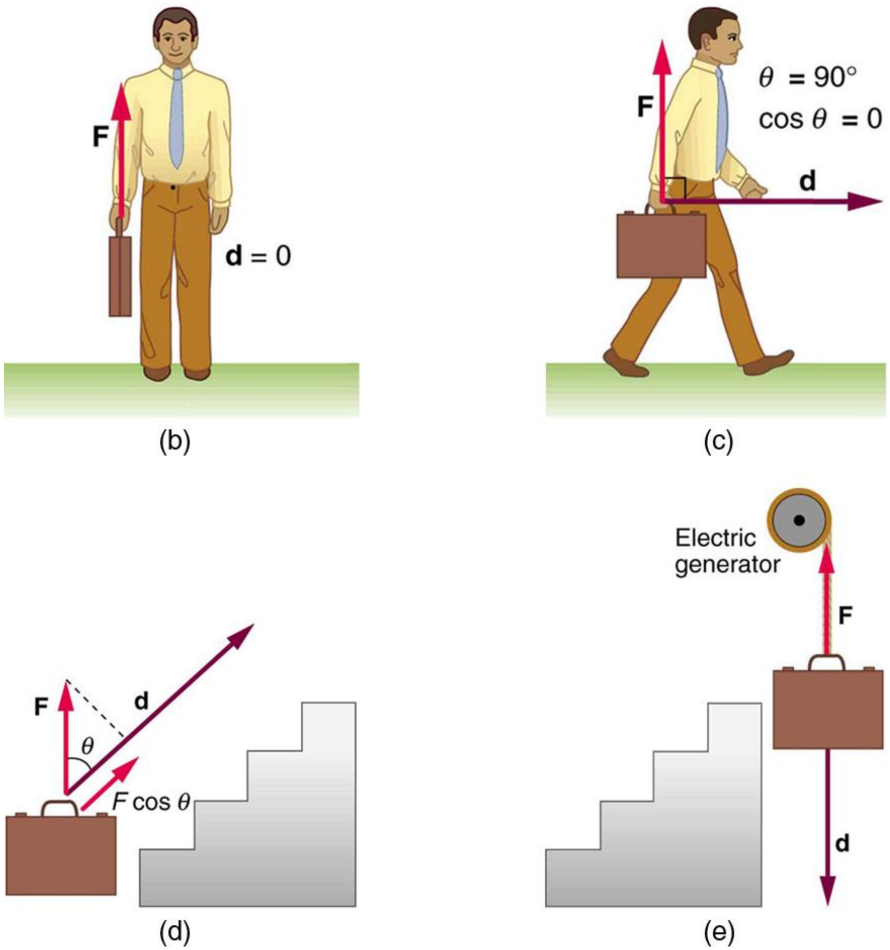
- Angle θ is the angle between the force and displacement.

- The unit of work is joule (J)

1 joule = 1 Newton.metre

i.e. 1 J = 1 N.m

Example 1



What is the work done by force F on the briefcase?

(b) 0

(c) 0

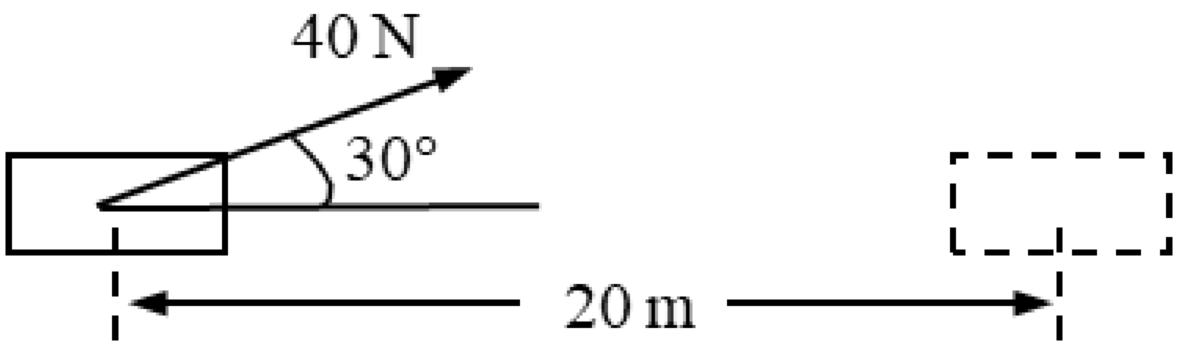
(d) Fd cosθ

(e) -Fd

Example 2

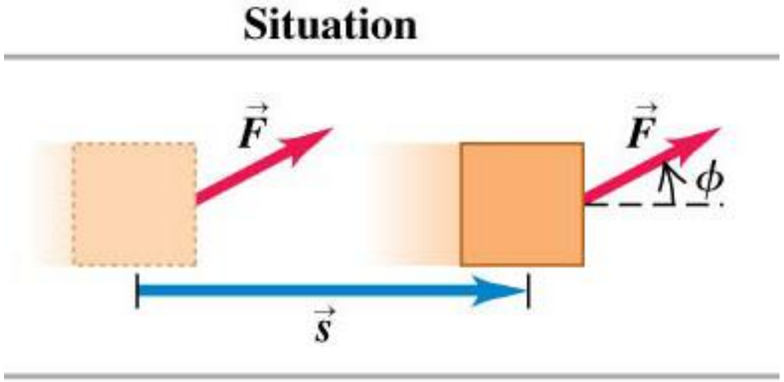
a) What is the work done when moving an object 20 m with a force of 40 N?

b) What is the work done if the force is applied at a 30^o angle to the displacement?

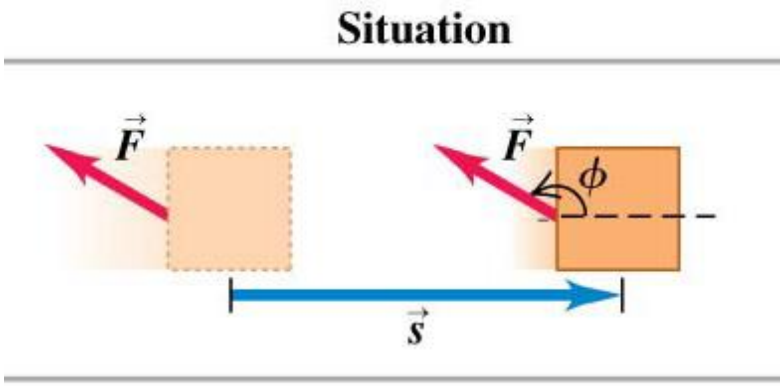


Work: positive or negative

- When the applied force has a component in the direction of the displacement, work is positive.



- When the applied force has a component opposite to the direction of the displacement, work is negative.



Example 3: Work done by more than one force

a) What is the work done in moving a carton box 20 m with a force of 500 N when a frictional force of 100 N opposes the motion?

b) How much work is required to overcome the friction?

c) What is the total energy required for the task?

Work-Energy theorem

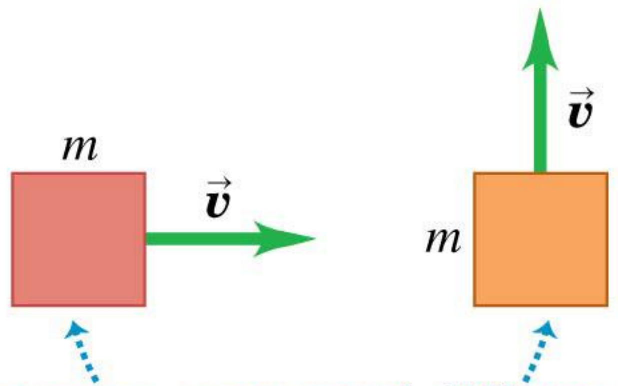
- The Work-Energy Theorem states that the work done by all forces acting on a particle equals to the change in the kinetic energy of the particle
- Work is done by the net (or resultant) force
- Kinetic energy is energy related to motion
- Energy is a quantitative property that must be transferred to an object in order to perform work
- Energy is the ability to do work
- Energy is a scalar quantity and appears in many different forms

Kinetic energy

- Kinetic energy is the energy associated with the state of motion of an object

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

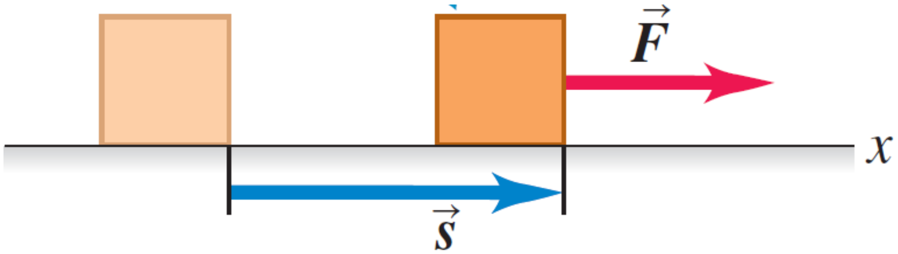
- Kinetic energy does not depend on the direction of motion
- When an object is at rest (stationery), it has zero kinetic energy



Same mass, same speed, different directions of motion: *same* kinetic energy

Work-Energy theorem (2)

- The work done by the net force on a body equals to the change in its kinetic energy:



... the work done by the force on the particle is $W = Fs$.

$$\boxed{W = Fs = KE_2 - KE_1 = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2}$$

Example 4

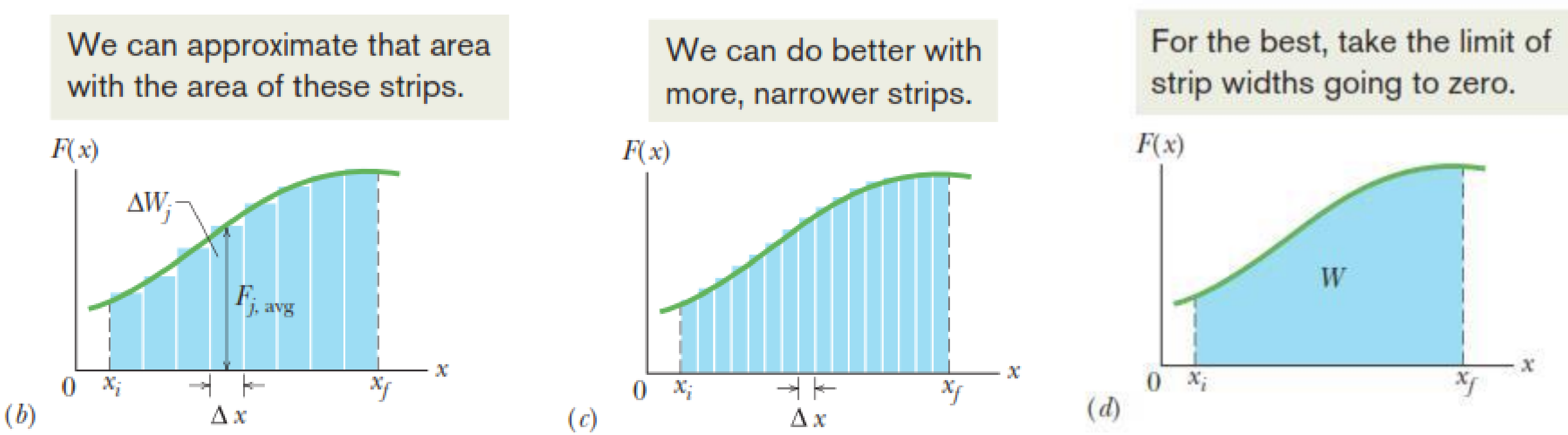
a) How much work is done by a constant force on a mass of 5.0 kg, which results in a change in velocity from 2.0 m/s to 4.0 m/s?

b) If the object travels a distance of 20 m, what were the applied force and the resulting acceleration?

Work with varying force

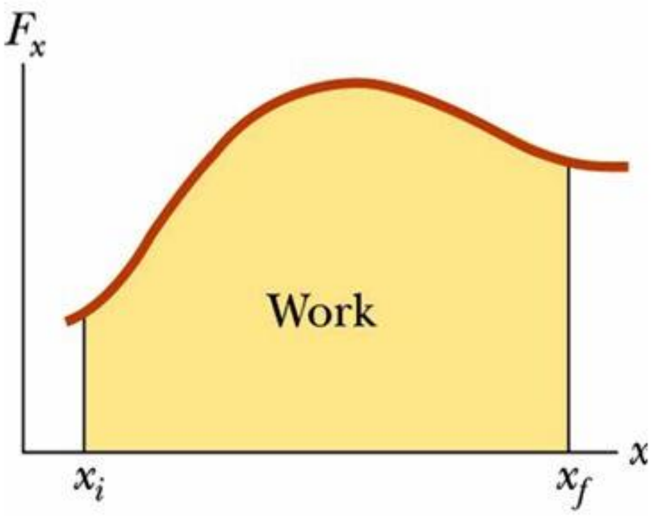
- Up until now we have assumed that force was constant
- If the force is varying use integration

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



Work with varying force (2)

- The work done is equal to the area under the curve



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

- If the force is constant $W = F_x(x_f - x_i) = F_x s$

Springs

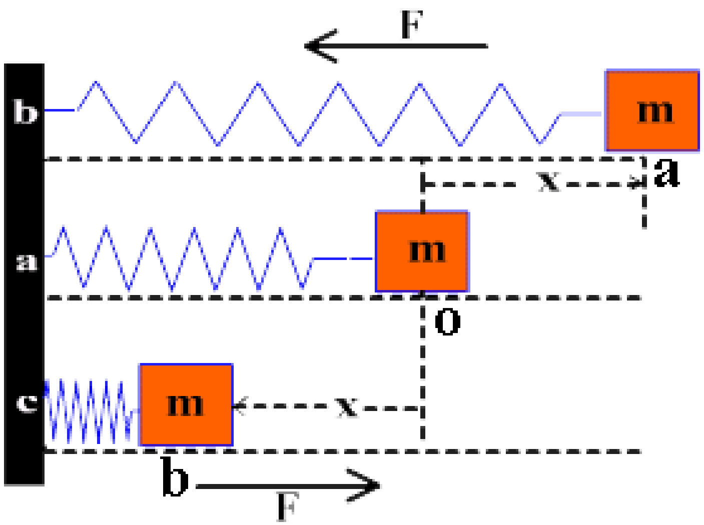
- Consider a mass on the end of a spring with *force constant k*
- Hook’s law says that for a displacement of x from the equilibrium position, it experiences a restoring force:
- Force needed to extend or compress a spring

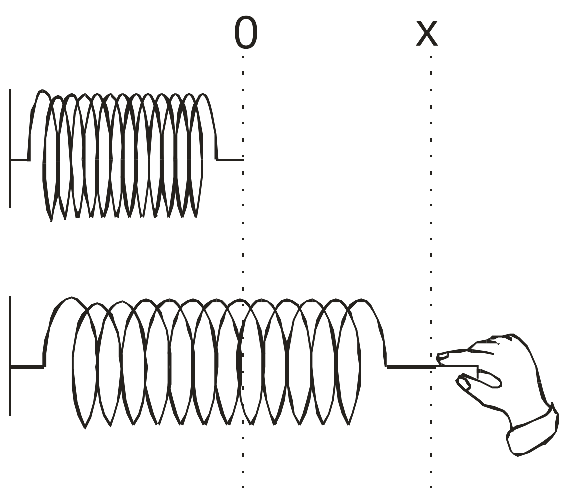
$$F_x = kx$$

- Therefore the work done:

$$W = \int_{x_i}^{x_f} F_x\,dx = \int_0^x kx\,dx = \frac{1}{2}kx^2$$

- This work is the potential energy stored in spring or any elastic object due to deformation





Example 5

A spring with a spring constant $k = 20$ N/m is compressed by a distance of 0.1 m from its equilibrium position. If a mass of 0.2 kg is placed on the spring and released, what is the maximum speed attained by the mass as it oscillates back and forth?

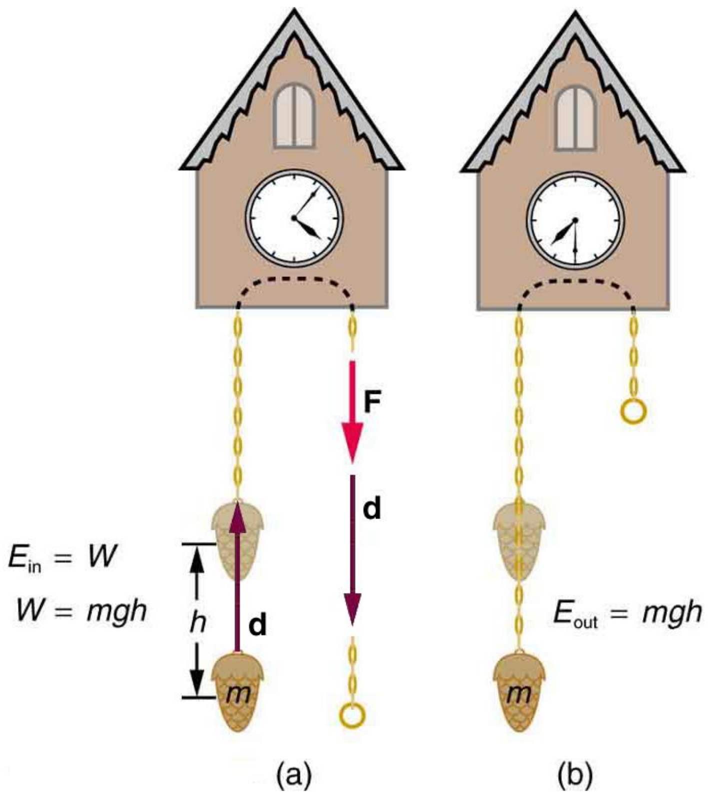
Potential energy and gravity

- Moving an object up or down while under the influence of a gravitation force involves work

- Work must be done on the object to lift it upwards (W > 0)

$$W = F.s = m.g.(h - 0) = mgh$$

- This work done is stored as potential energy (U) in the gravitational field of the Earth



Gravitational potential energy

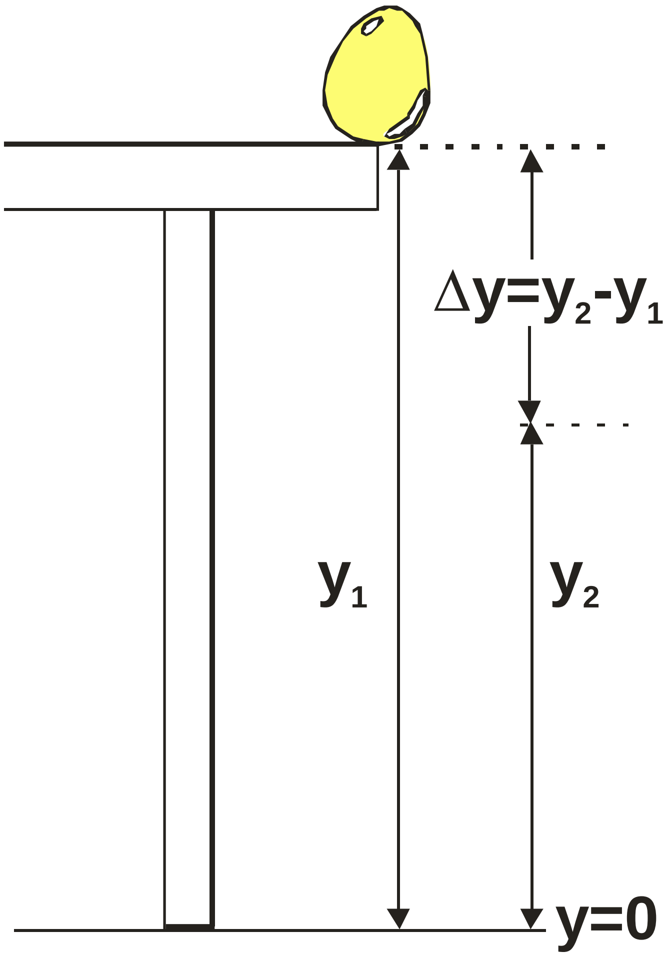
- This is the potential for gravity to do work
- Gravitational potential energy is

$$U_{grav} = mgy$$

- When the object falls from y_1 to y_2, the change in gravitation potential energy is

$$\begin{aligned}\Delta U_{grav} &= U_2 - U_1 \\ &= mgy_2 - mgy_1\end{aligned}$$

- When the object falls, the work done by gravity is positive and U_{grav} decreases. This is how much work can potentially be created by gravity



Example 6

If a ball of 200 g is thrown upwards with an initial velocity of 20 m/s, what maximum height will it reach?

Power

Power is the rate at which work is done over time

- Power is a scalar quantity
- Power is the rate at which energy is spent or gained
- Units of watts (W)

  1 W = 1 J/s

$$P = \frac{W}{\Delta t} = \frac{\mathrm{F.s.cos}\theta}{\Delta t}$$

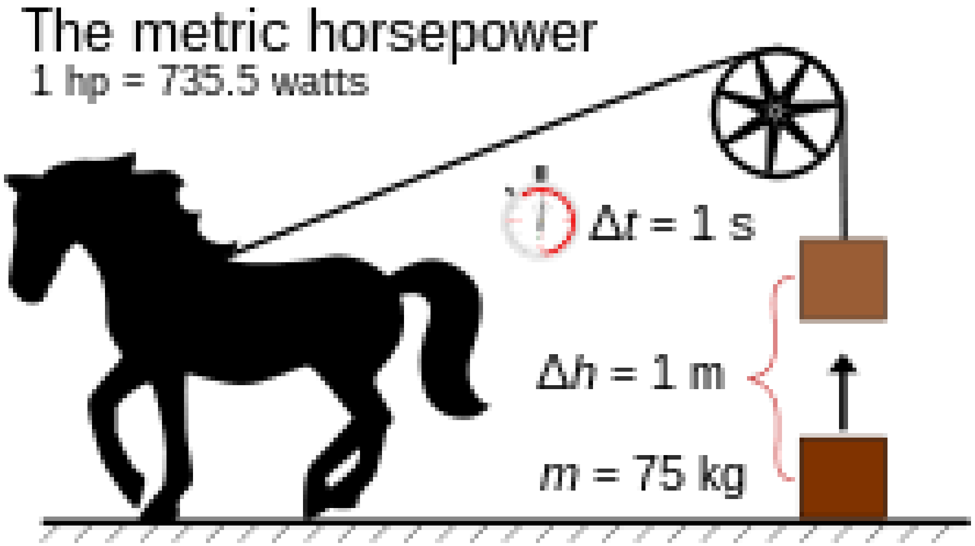
Power (2)

Average power

$$P_{average} = \bar{P} = \frac{W}{\Delta t}$$

Instantaneous power

$$P = \frac{dW}{dt}$$



Mechanical horsepower

$$1 \text{ horsepower} = \frac{W}{\Delta t} = \frac{mg\Delta h}{\Delta t} = 746 \text{ W}$$

Note: non-metric units are a mess. Use SI units!

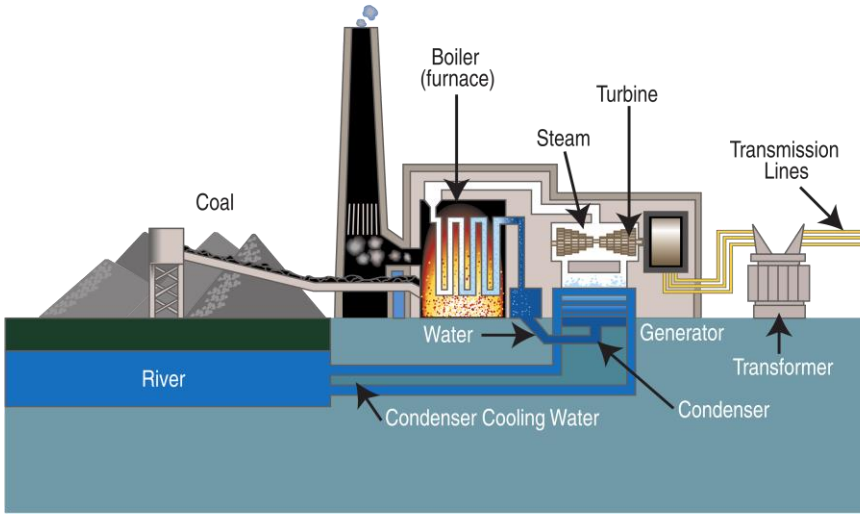
Example 7

A student participates in the annual UTS Tower climb, which has a height of 120 m. She completes the run in 8.0 minutes, what is the average power needed to take her to the top if the mass of the student is 60 kg?

Conservation of energy

- The principle of the energy conservation states that:

  Energy can never be created or destroyed; it can only be transformed from one state to another.



$$\Delta KE + \Delta U + \Delta E_{\text{internal}} = 0$$

- $\Delta E_{\text{internal}}$ is the change in internal energy of the system, i.e. energy on microscopic scale such as kinetic energy due to the motion of molecules/atoms

Example 8

A pump is tasked with lifting 1000 kg of water per minute from a well that is 8.0 m deep and ejecting it with a speed of 5.0 m/s.

a. How much work is required per minute to lift the water?

b. How much work is involved in imparting kinetic energy to the water?

c. What is the power output of the pump?