Theme 6: Work and Energy

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Work - force, work done, rate of doing work
- Energy - forms of energy - kinetic energy and potential energy, conversion of energy

Crocodiles

For many of us, the picture or thought of a crocodile would bring an image of long jaws with sharp long teeth. If one gets stuck between those, it would not be possible to escape.

Fig. 6.1, Mouth of a crocodile from the Australia Zoo; Image by Sebastian Wallroth via Wikimedia Commons

One would imagine this strong creature to have a heavy diet but that is not true. A crocodile can survive on food, which is one fourth of its body mass for the entire year. If you compare this with humans, depending on the culture, lifestyle, etc., we consume anywhere from 2 to 10 times our body mass. Crocodiles are one of the most efficient creatures known. What makes them efficient? Unlike humans, they are cold blooded and hence do not need to invest energy in maintaining their body temperature. They also don't have much of a brain, which in humans consumes a big portion of the energy. While our brain weighs around 2% of the whole body and occupies space in a similar range, it uses up around 20% of the energy consumed.

If you trace back the root source of this energy, it is an interesting revelation that the root source of the energy obtained by the crocodile as well as humans is the same. In fact, almost all the energy on Earth is sourced from the Sun. Earth receives this energy in the form of radiation and it later gets converted and used in various forms through a series of energy conversion processes. Conversion of energy from one form to another is an integrated part of every action happening around us.

During the Renaissance period, Galileo discovered one such instrument, which demonstrates this conversion of energy in a periodic manner and also became the basis of the design of this machine to measure the quantity called time.

Case Study A - Pendulum

A pendulum is a simple set-up powered by the conversion of potential energy to kinetic energy and vice versa. A pendulum has a weight suspended from a pivot that can freely swing back and forth. Fig. 6.2 shows a simple pendulum.

When the pendulum is displaced from its mean position, potential energy is stored in the system and it gets converted into kinetic energy as the pendulum tries to come back to its mean position. As the pendulum travels to the other side of the arc, the kinetic energy is transformed to potential energy. The conversion of potential energy to kinetic energy and vice versa continues to happen throughout the motion of the pendulum. In the absence of air drag and frictional force at the pivot, the pendulum would swing forever.

The time taken by the pendulum to complete one back and forth motion (one oscillation) is called the period of the pendulum. The distance between the mean position of the pendulum and one of the extreme points is known as the amplitude of the pendulum.

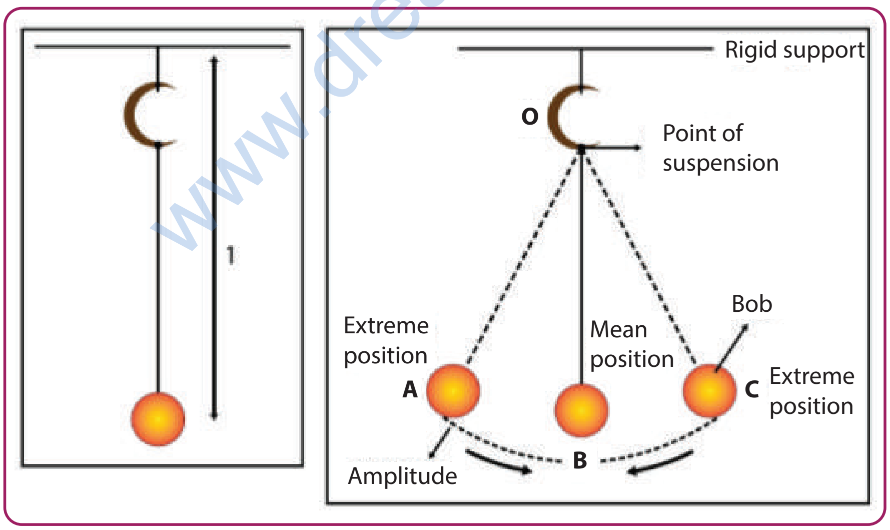


Fig. 6.2, A simple pendulum

Question 1

Fig. 6.3 shows a simple pendulum setup, where a ring magnet is freely suspended using some string. The mass at the bottom of the pendulum can be increased by attaching more magnets.

Nasir tried to determine how the period of the pendulum varies with mass, length of the string and amplitude of the pendulum. He varied each of these three variables one at a time and kept all other variables constant. Fig. 6.4 to Fig. 6.6 shows the plots of Nasir's experiment.

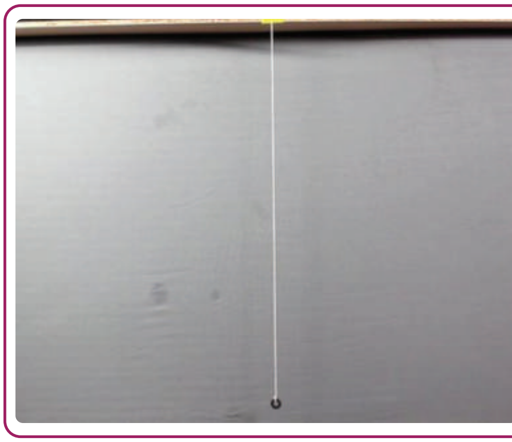


Fig. 6.3, A simple pendulum setup using a ring magnet and a cotton thread.

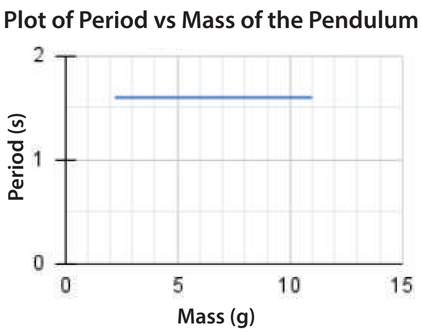


Fig. 6.4, Vary mass and observe the period; amplitude kept constant as 15 cm and length as 60 cm.

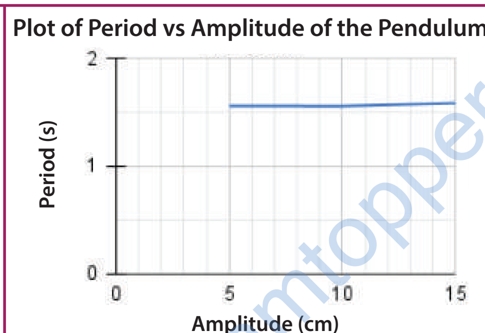


Fig. 6.5, Vary amplitude and observe the period; mass kept constant as 2.2 g and length as 60 cm.

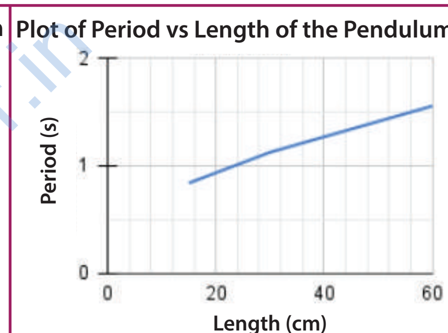


Fig. 6.6, Vary length and observe the period; amplitude kept constant as 15 cm and mass as 2.2 g.

From Nasir's experimental data, infer the parameter(/s) that decide(/s) the period of the pendulum. You may select more than one option from the list below.

a. Mass
b. Length
c. Amplitude

Answer

Question 2

Another parameter related to the pendulum is the speed at which it moves. The average speed of the pendulum can be calculated as twice the length of the arc it traverses in one cycle, divided by the period.

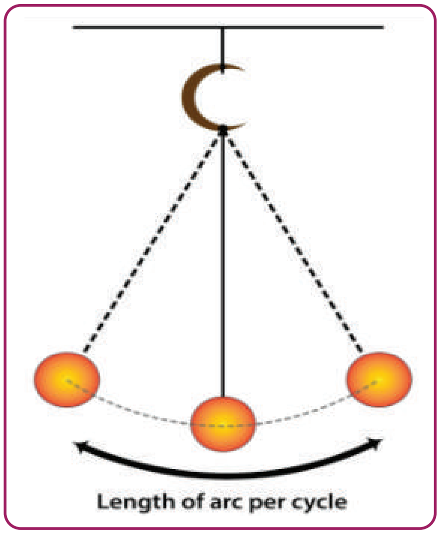
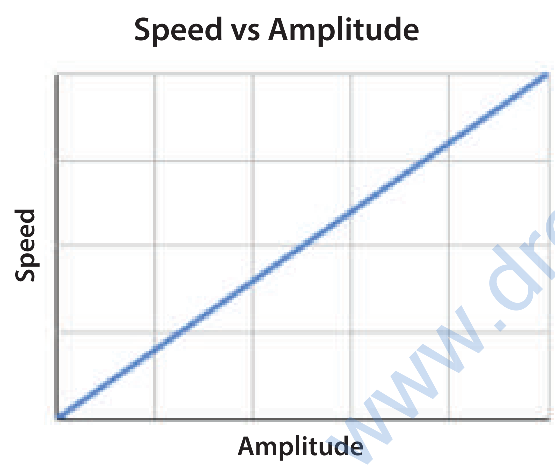


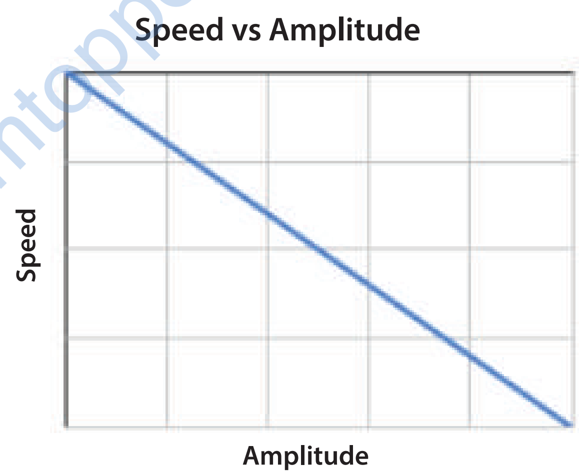
Fig. 6.7, Length of the arc of the pendulum

$$\text{Speed of pendulum} = \frac{2 \times (\text{Length of arc})}{\text{Period}}$$

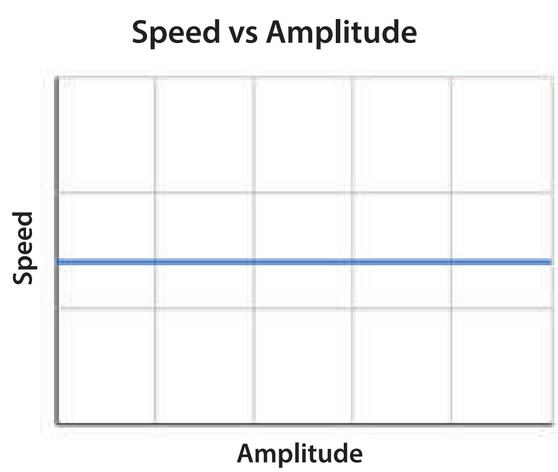
Based on the results of Nasir's experiment, predict how the speed would vary as we vary the amplitude of the pendulum bob. Choose one graph out of the four graphs show that correctly depicts your prediction.



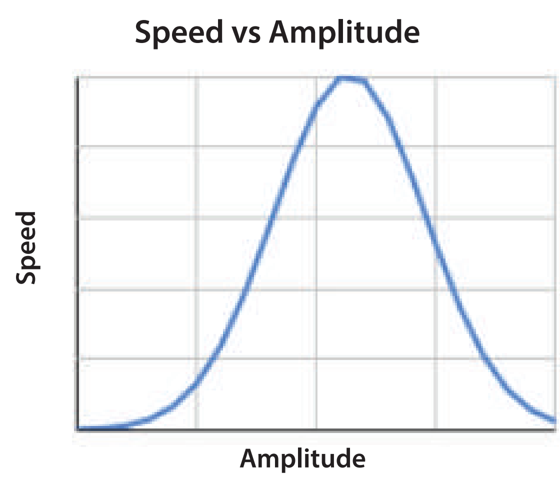
Answer option A



Answer option B



Answer option C



Answer option D

How do you think this study helped in improving the design of clocks? Write your answer in the space provided below.

Note: Thermal expansion and contraction refers to the change in the dimensions (volume, area or shape) of the material with respect to the change in temperature.

Answer

Storage of Energy

The cheetah is the fastest running land animal. It can achieve a peak speed of ~110 km/h, which is almost double of what a tiger can achieve. However, a cheetah can sustain this speed for not more than 20 to 30 seconds. In fact, it needs to rest for a long time after a sprint at peak speed, which is why it sometimes gets bullied by other carnivores and has to let go of what it hunts and earns the hard way.

Fig. 6.14, Cheetah on the road in Lower Sabie, Kruger NP, South Africa;
Image by Ellicrum via Wikimedia Commons

Will a tiger and cheetah require the same amount of energy? What about their energy usage per unit time? Because of the difference in the amount of energy we need and the rate at which it is spent, it is necessary to have a way to store energy. The grandfather clock can run for a longer time without being rewound, if it can store more energy. The entire transport industry runs mostly on stored chemical energy of fuels, most of which are not renewable. Though we desire to replace these by renewable sources, there are many unsolved problems in harnessing renewable sources of energy. One of the problems is the irregularity in the size and frequency at which we receive energy from renewable sources. Every day is not a sunny day and every day is not a windy day either! One of the methods of storing the energy received on a windy/sunny day to use on a calm/cloudy day is Pumped Hydroelectric Storage (also referred to as PSH or PHES).

Case Study C - Pumped Hydroelectric Storage

A pumped hydroelectric storage (PHS) has two reservoirs of water at different heights. During the times of the year when renewable sources of energy like solar or wind are easily available, electricity is produced using these sources to fulfil the electricity needs of that region. The surplus energy which remains unused is stored by pumping the water from the lower reservoir to the upper. The water from the upper reservoir is made to fall down to convert to electric energy during the days when demand for electricity is high and the availability of the renewable sources is low.

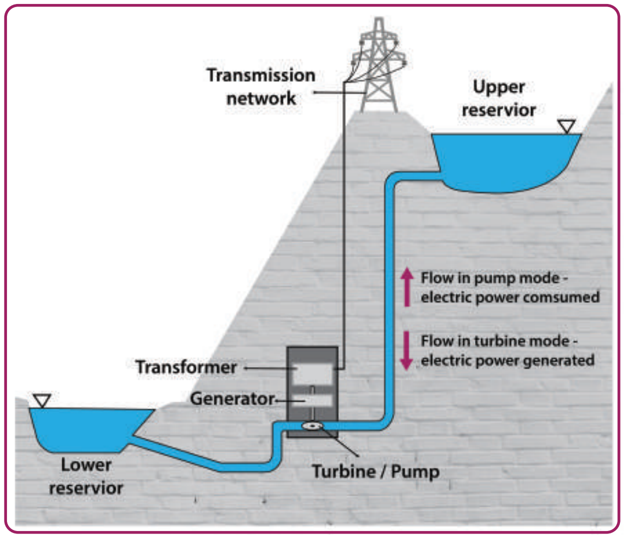


Fig. 6.15, Schematic of pumped hydroelectric storage system

Question 8

i. Which of the following parameter(/s) can be changed to maximise the amount of energy stored in a PHS? You may select more than one parameter.

a. Capacity of the upper reservoir

b. Using all the renewable energy and not just surplus energy, to pump the water up

c. Height of the reservoirs from mean sea level

d. Height difference between the two reservoirs

Answer

ii. What will happen to the storage capacity (in terms of energy) of the PHS if saline water is used instead of plain water? Write your answer along with a justification in the space provided.

Answer

Question 9

PHS is one of the biggest storages of energy discovered so far. Note the electric energy stored by batteries cannot match the amount of energy stored by PHS. However, the installation of a PHS has certain geographical requirements. Which of the following is not a necessary requirement/constraint for a PHS to be feasible? You may select more than one option.

a. High elevation / mountains	b. River/lake	Answer
c. Dense forest	d. High speed wind	

Question 10

A PHS is installed in Puttenahalli with the upper reservoir having a storage capacity of 1000 m^3 and located 100 m above the lower reservoir. This region experiences high speed wind for around 3.25 months in a year, with an average of ~8 hours of wind per day. To simplify calculations, the number of windy days may be rounded off to 100 days. During the windy months, 75% of the electric energy produced from wind is sufficient to meet the electricity needs of Puttenahalli. The rest can be stored for future use.

For the following questions, write your answers in the space provided.

i. How many litres of water should be pumped into the reservoir in one day (on an average), such that the entire reservoir is filled during the windy months? Assume that it is fully empty when the windy season starts. Note that 1 m^3 = 1000 litres.

Answer

ii. How much water should be pumped every second to meet the per day rate? Recall that only unused electric energy gets stored. Round off the answer to the first decimal place after the decimal point.

Answer

iii. As the water gets pumped to the upper reservoir, it gains gravitational potential energy. If it is pumped at the rate calculated in the previous question, how much energy gets stored every second? You may assume that 1 litre of water has a mass of 1 kg. Acceleration due to gravity can be approximated to 10 m/s² to simplify calculations.

Answer

iv. The electric motor for pumping the water to the upper reservoir has to be selected. The mechanical power generated by an electric motor is often specified in terms of horsepower or hp. 1 hp = 746 Watts = 746 Joules/second. The mechanical power of 4 motors available in Puttenahalli are given below. Which of these would be most suitable for meeting their requirement of the rate of pumping?

a. 1 hp	b. 1.5 hp
c. 2 hp	d. 3 hp

Answer

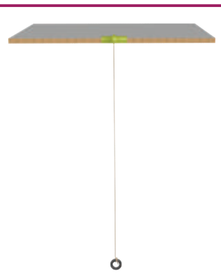
Question 11

What would happen if they select a motor with a mechanical power rating lower than their required rate?

a. PHS can't be set up
b. Water cannot be pumped to the upper reservoir
c. Less energy will be used in pumping and hence more energy will be available for storing
d. Some unused wind energy will not get stored

Answer

Exploration Pathway

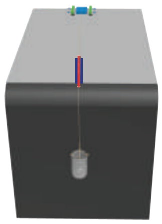


Motion - Periodic

In this splendidly simple and iconic TACtivity, you will make a classic pendulum, with a string and weight, used to measure time for centuries and the very basis of our "grandfather" clocks! Moreover, the constant to-and-fro motion, also known as Oscillatory Motion or Simple Harmonic Motion, is a wonderful phenomenon to experience and make measurements on.

Wave Turbine Model

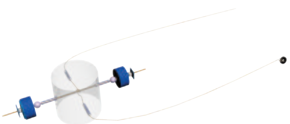
Humans have learnt how to harness energy from various sources, to make certain tasks mechanised, produce electricity etc. The energy is often harnessed through the use of turbines. In an increasingly warming planet, it is imperative that we expand our capacity of harnessing renewable sources of power. One such example is a Wave Turbine, as described above.



Trolley Model

Newton's Second Law of Motion talks about how the net force acting on a body is directly proportional to the mass of the body and acceleration it experiences.

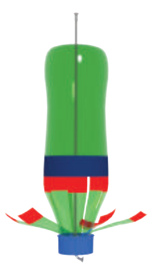
In this ingenious TACtivity, we use our own Hand Cart to conduct a series of experiments to discover for yourself the relationship between mass and acceleration.



Flywheel Model

A flywheel is a mechanical device used to store potential energy. It is comprised of a heavy disc or wheel attached to a rotating shaft. The wheel rotates for a longer time when there is less friction.

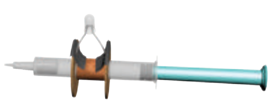
In this TACtivity, we will make a flywheel model, using a plastic bottle, bottle caps, a piece of thread, beads, wooden skewer and foam pieces, and observe the flywheel descend. What does the speed of descent depend on? This model beautifully demonstrates both the conservation of energy and friction.



Wind Turbine Model

Humans have learnt how to harness energy from various sources, to make certain tasks mechanised, produce electricity etc. The energy is often harnessed through the use of turbines. In an increasingly warming planet, it is imperative that we expand our capacity of harnessing renewable sources of power. One such example is a Wind Turbine.

In this TACtivity, we make a Wind Turbine Model, using a waste plastic bottle and a cycle spoke. Place the bottle and spoke assembly under a fast-spinning ceiling fan and enjoy seeing the turbine spin rapidly!



Generator Model

Using a 5 ml syringe as the core, we wind 35-gauge insulated copper wire making 500 loops on it. Within the syringe, we place a magnet that moves as we shake the syringe. The two ends of the copper wire are connected to an LED. As the syringe is moved up and down, the LED should light up!