Episode 214: Work done by a force

In this episode, students have to learn to think of force as a mechanism by which energy is transferred from one body to another. This only occurs when the force moves in the direction of the force.

Summary

Discussion: Introductory discussion. (10 minutes)

**Student experiment: Efficiency of a ramp. (25 minutes)**

Student questions: Calculations of work done. (30 minutes)

Discussion:

Introductory discussion

For some students this will be a revision session. Others may be less familiar with the concepts. Use questions and answers to establish the knowledge of the group.

We say that work is done by a force when the object concerned moves in the direction of the force, and the force thereby transfers energy from one object to another. You can be a typical physics teacher and use a board rubber to illustrate your point about energy gain. Alternatively, use some other more interesting object such as a model Thunderbird One. The following questions should allow you to draw out the ideas used in the experiment which follows:
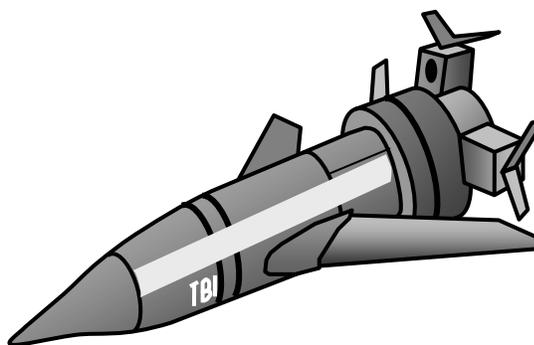
What sort of energy is gained by raising a mass (board rubber etc)? (GPE)

What is the force acting against the movement? (mg) We say that the lifting force is doing work against gravity. Some students may feel that it takes a larger force than mg to raise the object; however, if the object is raised at a steady speed, it is in equilibrium and the lifting force will just balance weight. This of course ignores any air resistance etc

What is g? (You are looking for *gravitational field strength* here, not *acceleration due to gravity*; you may need to draw this point out.)

What two factors will determine how much energy you lose (and hence the energy transferred to the object)? (The size of the force and the distance h moved in the direction of the force.)

Can you state the equation which gives the energy gained? (mgh)

Hence how much energy is required to lift object height h? (mgh)

This suggests that energy transferred = force $\times$ distance moved in direction of force. This is known as the work done by the force. In fact, we have used the fact that students are familiar with the equation GPE = mgh to lead them to the more general equation for work done. You should now point out that mgh is simply a particular case of work done.

You can now push the board rubber or thunderbird across the lab bench to show work being done against a frictional force. In this case, the energy transferred ends up as heat.

Student experiment:

Efficiency of a ramp

You may want to show the apparatus set up before the students attempt this experiment and show them how to get the block moving smoothly. The values of the masses to overcome friction depend on the apparatus you are using and therefore the experiment needs to be trialled before the lesson. Using a pulley system should allow the students to get reasonably consistent results.

This simple experiment is made more interesting by revising the resolution of forces and considering the total work done to be the sum of work against gravity and work against friction. This concept is reiterated in the questions (below).
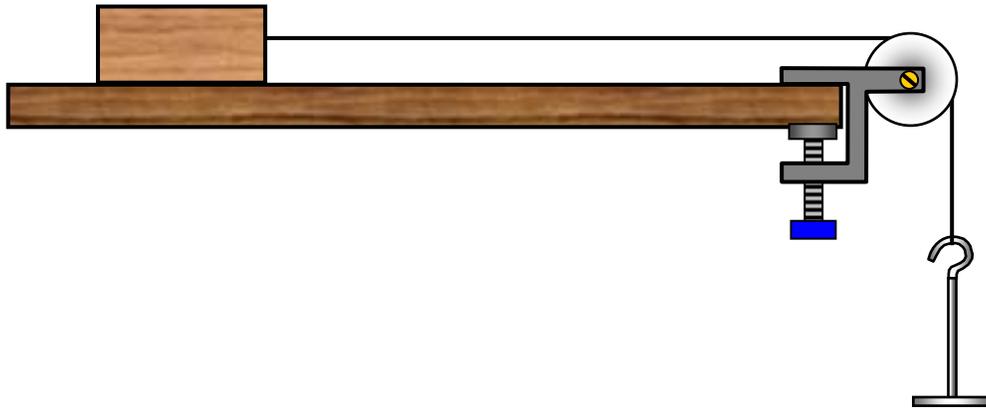
TAP 214-1: Work done in raising a weight using a ramp
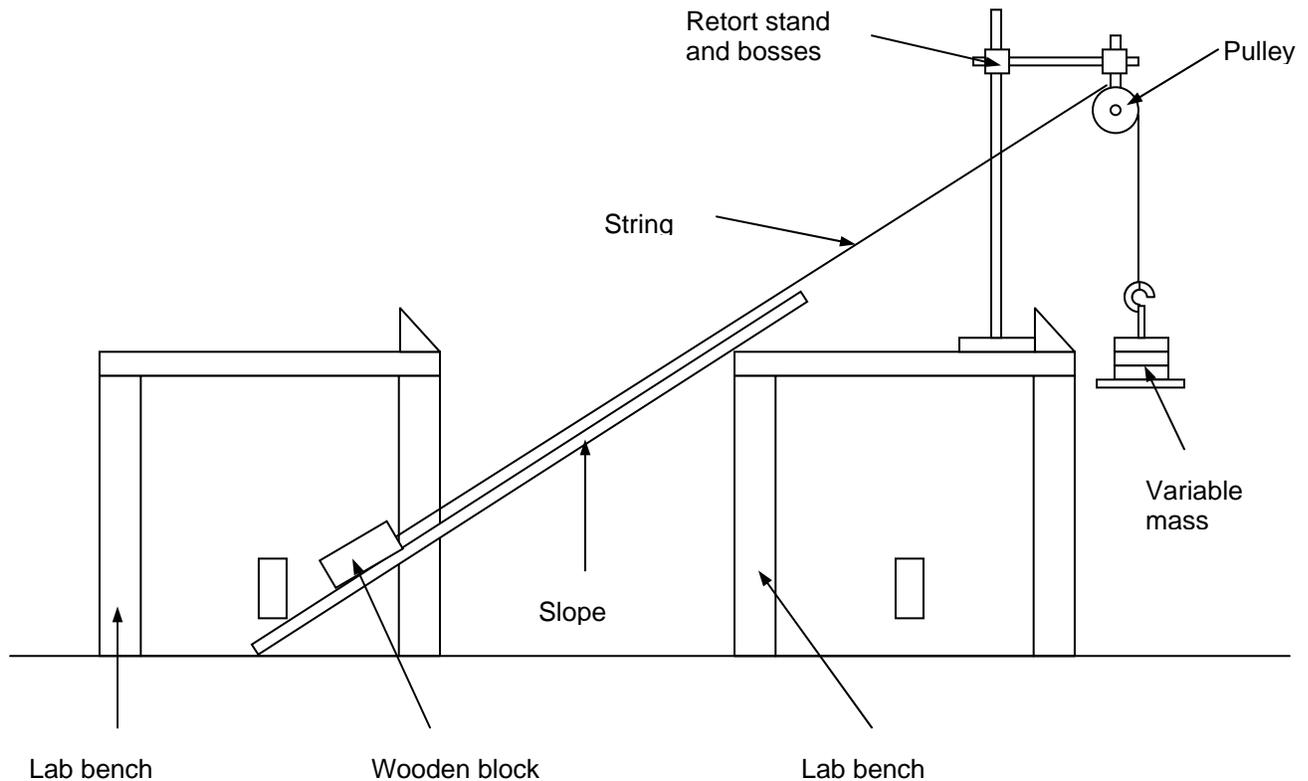
Student questions:

Calculations of work done

You may choose to use some of these in the class as discussion questions, or as worked examples.

TAP 214-2: Along the flat and up the hill

TAP 214-1: Work done in raising a weight using a ramp

Set up the apparatus as shown in the diagram.

- Measure and record the mass of the wooden block.

- Mark the position of the wooden block at the bottom of the slope.

- Carefully add mass to the end of the string until the wooden block *just* starts to move. Experiment until you are happy that the block is just moving up the slope. Record the pulling mass.

- When the block comes to a rest (usually because the pulling mass has hit the floor) measure how far the block has moved along the slope.

- Calculate the work done in pulling the block up the slope.

- Measure how high the wooden block has been raised (i.e. the vertical distance moved). Think carefully how you might do this accurately.

- Calculate the gravitational potential energy gained by the block.

- Compare the work done by the falling variable mass to the GPE gained. What do you notice? Can you explain this?

Calculate the efficiency of the ramp system in lifting the weight:

efficiency = potential energy gained × 100%
                    work done

Analysis of forces on the block:
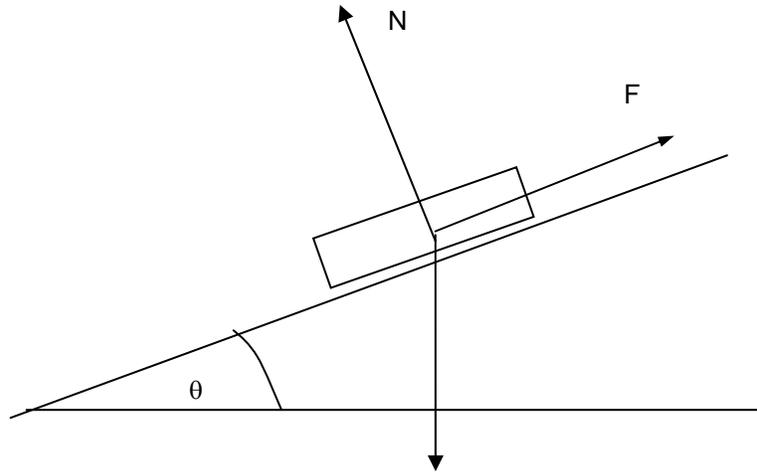
- Copy the diagram above and add the frictional force.

- At equilibrium, when the block is moving up the slope with constant velocity:

magnitude of force F = magnitude of frictional force + component of W acting down the slope

Use this relationship to estimate the frictional force acting down the slope.

- Calculate the work done *against friction* in pulling the block up the slope.

- If the block is pulled very slowly up the ramp the expression:

Potential energy gained + work done against friction = total work done

is reasonably accurate.

Test this expression using your results and suggest a reason for any discrepancies.

TAP 214- 2: Along the flat and up the hill

Think carefully, and calculate a little.

Two speeds, one principle.

Travelling slowly, at about 5 miles an hour, the retarding forces acting on a cyclist are about 5 N.

1.   What propulsive force must the cyclist provide to travel at constant speed?

2.   How much energy does the cyclist have to provide to cover 5 m?

At a higher speed, nearly 10 mph the retarding forces are much larger, nearly 8 N.

3.   Write down the propulsive force required at this speed.

4.   Calculate the energy the cyclist must provide every to cover 5 m at this constant speed.

Climbing a hill at a steady speed of 5 mph the cyclist finds herself perspiring rather more than on the flat. The mass of the cycle plus cyclist is 80 kg. The ergometer pedals fitted report the energy supplied to the bicycle as 185 J to cover a 5 m stretch of road.

5.   How much energy is used to lift the cyclist uphill?

6. How much height does she gain in travelling along the 5 m stretch of road?

7. How much energy would she have to provide to cover this same stretch of road at 10 mph?

8. What is the retarding force acting on her, when travelling uphill at 10 mph?

9. Draw a vector diagram for the retarding forces (due to drag and gravity) acting on her at 10 mph.

10. Calculate the retarding force due to the slope as a fraction of her weight. Comment on the advantages of using the slope of the hill rather than lifting bike and rider vertically by the same distance

Practical advice

These are intended to start at a very low level, building up to thinking about forces not along the line of movement affecting energy changes.

Social and human context

The energy to surmount even a small hill has appreciable effects on the power requirements. So, prior to the invention of the internal combustion engine, with its very high power / all up-weight ratio, engineers had to respect the landscape, trading larger distances covered for more gentle gradients.

Answers and worked solutions

1. Net force must be zero, so 5 N

2.

$$Work = force \times distance$$
$$= 5\,m \times 5\,N$$
$$= 25\,J$$

3.

Net force must be zero, so 8 N

4.

$$Work = force \times distance$$
$$= 5\,m \times 8\,N$$
$$= 40\,J$$

5.

$$energy\,to\,lift = energy\,supplied - energy\,dissipated$$
$$= 185\,J - 25\,J$$
$$= 160\,J$$

6.

$$Energy\ transferre\,d = m \times g \times \Delta h$$
$$\Delta h = \frac{160\ J}{80\,N \times 10\,N\,kg^{-1}}$$
$$= 0.2\ m$$

7.

$$energy\ supplied = energy\ to\ lift + energy\ dissipated$$
$$= 160\,J + 40\,J$$
$$= 200\,J$$

8.

$$Energy\ transferred = force \times distance$$

$$force = \frac{200\,J}{5\,m}$$

$$= 40\,N$$

9.

drag 8 N

32 N

retarding force
due to gravity
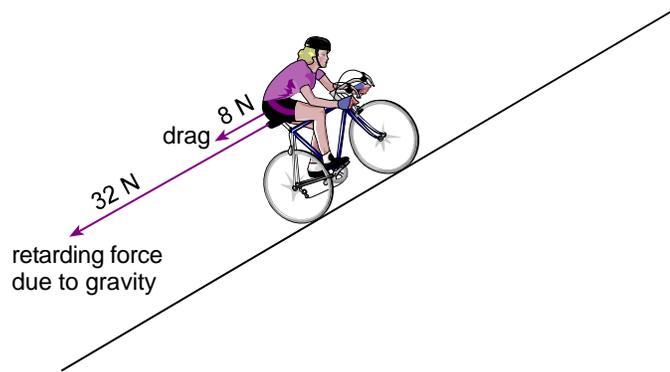
10.

$$ratio = \frac{32\,N}{800\,N} = 4\%$$

External references

This activity is taken from Advancing Physics, Chapter 9, Question 240W.