

## Episode 211: Newton's second law of motion

This episode concerns Newton's second law. Your students will probably have met the second law in the form  $F = ma$ ; many will have performed experiments to demonstrate the law. It is therefore useful to approach the experimental demonstration of the law as an exercise in data gathering and analysis. Using a simple set of apparatus should allow students to work individually or in pairs and critically consider the limits of the experiment as well as re-familiarising themselves with the second law.

### Summary

**Discussion: Revision of kinematics. (10 minutes)**

**Student investigation: Relationship between acceleration and force. (30 minutes)**

**Discussion: Looking at the results. (10 minutes)**

**Student questions: Using Newton's second law (30 minutes)**

### Discussion:

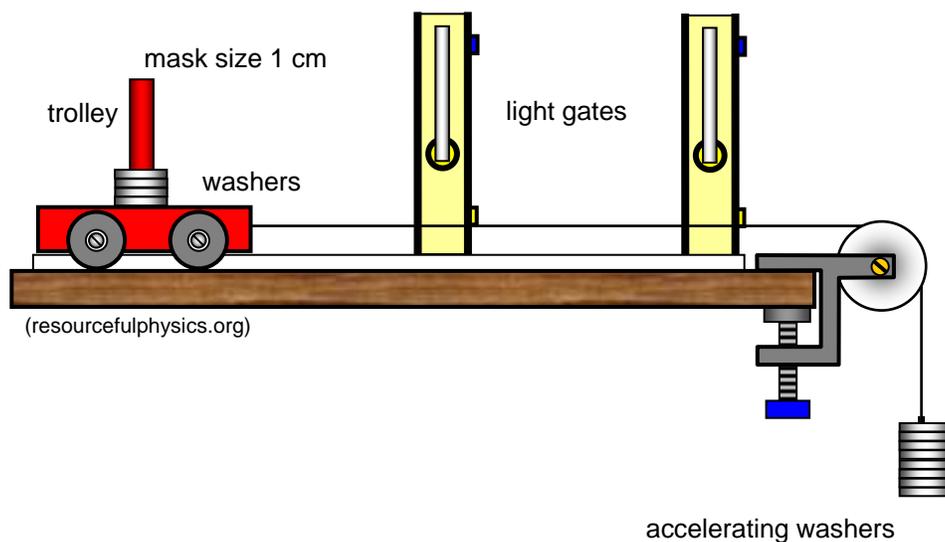
#### Revision of kinematics

Before embarking on the main activity it is useful to run through the equations of motion

(the 'SUVAT' equations) once again so that students will understand the 'recipe' they use to calculate acceleration. You want to establish that by referring to the equation  $s = ut + \frac{1}{2}at^2$  the acceleration of a body travelling distance  $s$  from rest is given by  $a = \frac{2s}{t^2}$ .

### Student experiment:

#### Relationship between acceleration and force



In this experiment, a trolley is accelerated by weights which are hanging on the end of a string which passes over a pulley. It is important to note that the mass which is being accelerated includes the mass of the weights on the end of the string.

After the preliminary discussion the students should be able to tackle this without too many difficulties. The questions at the end of the section are best attempted after the apparatus is cleared away and the students have drawn the graphs. You can use their responses as a basis for a plenary session in which further discussion of sources of error (timing – more difficult for shorter time intervals, non-uniform acceleration etc).

TAP 211-1: The effect of force and mass on the acceleration of an object

### **Discussion:**

#### **Looking at the results**

Discuss your students' results:

Do they find that acceleration is proportional to force, and inversely proportional to mass?

Numerically, are their results consistent with the equation  $F = ma$ ?

You may wish to point out that the experiment can only show proportionality. In other words, we can only conclude that  $F = kma$ , where  $k$  is a constant. In the SI system of units, we choose  $k = 1$ . This defines the Newton:  $1 \text{ N} = 1 \text{ kg m s}^{-2}$ .

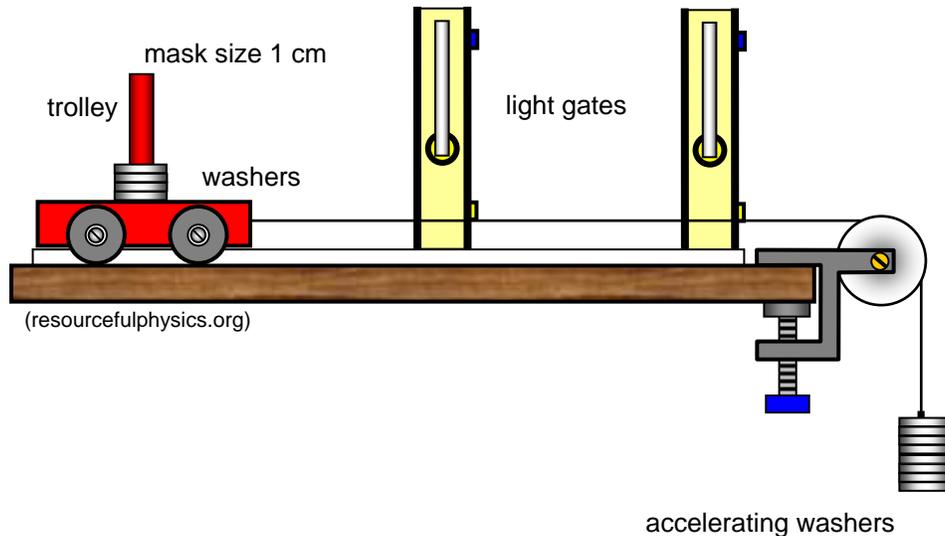
### **Student questions:**

#### **Using Newton's second law**

Make a selection from these questions: cut out those you think may be too trivial for some, and others (using resolved forces) which may confuse weaker students even though the concepts have already been covered. You may wish to reserve some of the questions for later use.

TAP 211-2: Newton's second law

## TAP 211- 1: The effect of force and mass on the acceleration of an object



### The aim of the experiment

The aim of this experiment is to investigate the effect of force and mass on the acceleration of an object, in this case a trolley.

### You will need

- ✓ a trolley,
- ✓ a white plastic track,
- ✓ a pulley,
- ✓ thread,
- ✓ twelve washers (mass 10 g each, or 10 g masses and a holder)
- ✓ metre rule
- ✓ light gates and timer or stopwatches

### What to do

Set up your apparatus as shown in the diagram. The trolley should be able to run for 0.6 m. This is the length over which the trolley accelerates. Compensate for friction by tilting the track slightly so that the trolley runs steadily down with no increase in speed when there is no force pulling it.

Start with ten of your twelve washers on the trolley and the other two on the thread hanging down.

The mass to be accelerated is the mass of the trolley and twelve washers while the accelerating force is the weight of the two suspended washers (0.2 N).

Allow the trolley to accelerate down the track and record the time taken: take two repeats and take an average.

Repeat the procedure by taking one washer off the trolley and adding it to the suspended washers – the accelerating force is now 0.3N (same total mass). Carry on until you have only two washers left on the trolley.

Calculate the acceleration of the trolley using  $a = 2 L/t^2$  where L is the distance between the light gates

**Draw up a table with the following headings:**

Accelerating force (N)	Total mass (kg)	time to travel L/s				acceleration = $2 L/t^2$ ( $m s^{-2}$ )
		1	2	3	mean	

Plot a graph of acceleration (y – axis) against force (x- axis).

Use the graph to answer the following questions:

- 1 From Newton's 2nd Law you would expect the graph of acceleration against force to be a straight line which passes through the origin.
- 2 Explain why you would expect this to be the case.
- 3 Explain what the gradient of the graph represents.
- 4 Calculate the gradient of the graph and explain whether it agrees with your answer to question (3).
- 5 Your results may show some scatter. Explain why this might be and the causes of any inaccuracy.
- 6 Does the experimental result support Newton's Second Law of Motion?

### Practical advice

The friction changes with different slope angles. It is best to try the experiment out first and decide if it is worth tilting the slope to friction compensate.

The acceleration could be measured directly with a motion sensor attached to a computer

### External references

This activity is taken from Resourceful Physics <http://resourcefulphysics.org/>

## TAP 211- 2: Newton's second law

Simple calculations and a little thinking.

An 80 kg skier has a force of 200 N exerted on him down the slope.

1. Calculate his acceleration down the slope.
2. Is the slope less than or more than 45°? Explain your answer.

An ice hockey player has a sudden impact force of 2000 N exerted on him due to unexpected collision with the wall. The mass of the player is 100 kg.

3. Find his acceleration.
4. Compare this with the acceleration when he free falls.

Coming out of a dive, 75 kg astronauts in training experience an acceleration of  $40 \text{ m s}^{-2}$ .

5. Calculate the force acting on them.
6. Compare this with the force which normally acts on them when stationary on Earth.
7. Why is it important that they are seated and strapped in before the dive ends?

A 50 g tennis ball may be accelerated at  $1000 \text{ m s}^{-2}$  to reach a service speed of 130 mph.

8. Calculate the force required to accelerate the ball.

9. Is your answer reasonable? Comment.

When a force of 200 N is exerted on an asteroid it accelerates at  $0.002 \text{ m s}^{-2}$ .

10. Find the mass of the asteroid.

### Practical advice

Some straightforward, 'get you started' questions.

### Social and human context

Enormous. You might challenge students to come up with a piece of mechanical engineering that does not involve Newton's laws – perhaps a pin board on the lab wall....

### Answers and worked solutions

1.

$$a = \frac{F}{m} = \frac{200 \text{ N}}{80 \text{ kg}} = 2.5 \text{ m s}^{-2}$$

2. Slope is less than  $45^\circ$  because at this angle, force down slope = weight /  $\sqrt{2}$ , which is greater than 200 N.

3.

$$a = \frac{2000 \text{ N}}{100 \text{ kg}} = 20 \text{ m s}^{-2}$$

4. Twice

5. 3000 N

6. Four times

7. Astronauts will be brought to rest at the end of the dive which may require the application of a large force resulting in injury.

8.  $F = ma = 0.050 \text{ kg} \times 1000 \text{ m s}^{-2} = 50 \text{ N}$
9. Not very large – as you can probably lift 250 N with one arm.
- 10.

$$m = \frac{200 \text{ N}}{0.002 \text{ m s}^{-2}} = 1.0 \times 10^5 \text{ kg}$$

### **External references**

This activity is taken from Advancing Physics Chapter 9, 160S