Catapult Challenge

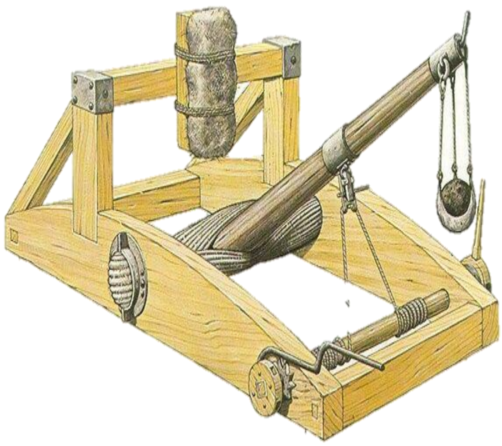
What exactly is a catapult?

A catapult is a machine that uses the principles of **mechanical advantage**, **energy transfer** and **projectile motion** to hurl an object (normally a stone) at a target. These devices were commonly used in history when besieging castles, stones thrown by the catapults could destroy the walls of the castle!

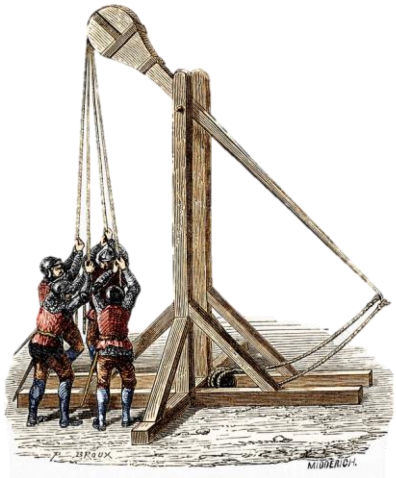
Hurling these big stones requires a lot of energy and as we know – **energy cannot be created or destroyed**. However, **energy can be converted** from one form to another. All catapults get their kinetic energy (energy needed to throw the stone) from an energy source:

$$\text{Input energy} \rightarrow \text{Output energy}$$
$$\text{Energy source} \rightarrow \text{Kinetic energy}$$

Here are three different examples of catapults from history – look at the pictures and see if you can identify the energy source!



The **Onager** was the main catapult used during Roman times. It used **twisted rope as the energy source**. As the rope is twisted, energy is stored as **elastic potential energy** – when you let go, the rope untwists, flinging the arm up which is then stopped by the crossbeam so the stone flies out. The elastic potential energy of the twisted rope is **converted into kinetic energy** in the stone.



The **Mangonel** replaced the Onager as the dominant siege engine in the early Medieval Period. **The energy source used here is humans**! The men pull down on one side of the pivot as hard as they can, causing the other end to swing around and throw out the stone. The **mechanical energy** provided by the humans pulling on the rope is **converted into kinetic energy** for the stone.

The **Trebuchet** was the most powerful siege engine used in the Medieval Period before the advent of gunpowder. A **counterweight was used as the energy source** – most often using a large basket filled with rocks. The counterweight is winched up and held there – when the counterweight drops, the other end of the arm swings up to throw the stone out. The **gravitational potential energy** of the counterweight is **converted into kinetic energy** in the stone.

Notice they all have long arms to throw the stone – this increases the **velocity** (remember: velocity is like speed but with a direction) of the stone when it is released. A larger velocity means that the stone will go further before it hits the ground, you will explore this in the next section.

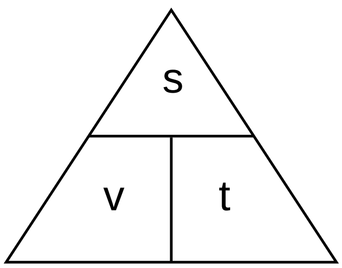
You can visualise this with your own arm – try throwing a ball from your elbow and then throwing the same ball from your shoulder. Which one goes further?

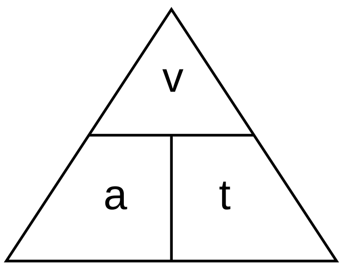
The length of the flinging arm provides a **mechanical advantage**. A longer arm allows for **more effective conversion** of the motion caused by the energy source, into the kinetic energy of the stone when it's thrown.

Projectile Motion

Projectile motion is the movement of an object flying through the air – the only force acting on it is **gravity**. The movement of the projectile is described as a **velocity** (speed in a given direction), measured in **metres per second**. The projectile accelerates towards the ground because of **gravity**. **Acceleration** is a measure of how quickly the velocity is increasing, measured in **metres per second per second**. Both of these quantities can be calculated with the two following equation triangles:

$$v = \frac{s}{t}$$





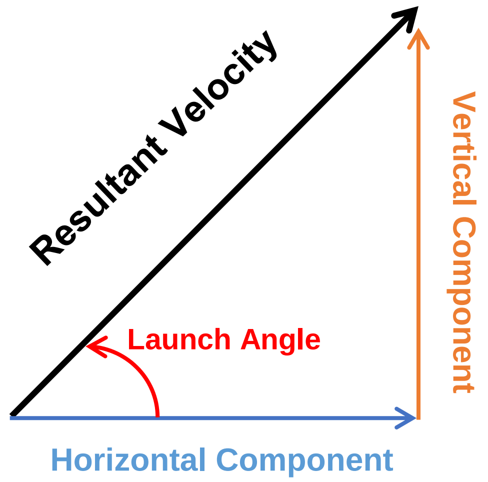
$$a = \frac{v}{t}$$

Symbol	Quantity	Units	Unit symbol
s	Distance	Metres	m
t	Time	Seconds	s
v	Velocity	Metres per second	m/s
a	Acceleration	Metres per second per second	m/s^2

If a catapult launches a projectile **horizontally** at **30m/s**, and it is recorded to fly for **5 seconds** before it hits the ground, we can find out how far it went:

$$v = \frac{s}{t} \xrightarrow{rearranges} s = v \times t = 30 \times 5 = 150\, meters$$

However, we know that a catapult doesn't just throw a stone out horizontally – it **throws it at an angle up and away**. When a projectile is thrown at an angle, its **total velocity** is a **combination** of its velocity upwards (**vertical component**) and its velocity away (**horizontal component**). This is shown in the diagram on the next page.



So why does it go further if we launch it at an angle? If we think about what the different **components** do by themselves we can see why they work best together.

If the **velocity** was just the **vertical component**, we'd be shooting it straight up in the air! It would go upwards but it wouldn't go anywhere sideways. It would go higher and spend longer in the air because **gravity has to accelerate against this upwards velocity** to pull it down to the ground.

If the **velocity** was just the **horizontal component**, we'd be shooting it out flat sideways like in the earlier example. It would go fast sideways but **gravity doesn't have any upwards velocity to decelerate** so it will hit the ground sooner.

If we **launch it at an angle** we **take advantage of both** of these components: we get a **sideways velocity** from the **horizontal component** and we get **more time in the air** from the **vertical component**.

The launch angle decides the sharing of these components – at **45 degrees**, we get an **equal share** of the horizontal and vertical components. This is the best launch angle for your catapults!

Design a Catapult of your own!

Now you have a better understanding of catapults and how they work, why not build your own? Down below is a simple way of making one from things around the house, but feel free to try a wide variety of designs. Maybe even see the difference and which one flings your objects the furthest!

Materials Needed:

- Lolly sticks
- Rubber bands
- A bottle lid
- Small object to launch (e.g. cotton balls)

Alternative materials:

- Pens and pencils instead of lolly sticks
- A spoon can be used instead of a lolly stick and bottle cap

Method:

1. Stack some lolly sticks together, about 5, and rubber band the ends.
2. Stack 2 lolly sticks together and wrap a rubber band around the very end.
3. Pull the 2 lolly sticks apart a bit to form a V-shape. Place the stack of 5 lolly sticks between the 2 lolly sticks.
4. Wrap a rubber band around all of the lolly sticks to hold the catapult together.
5. Glue a bottle lid on to serve as a launching platform.
6. Push down on the top lolly stick and release to launch an object from the milk cap.

Here are some other catapult designs you can try:

Record your distances

Now your catapult is ready to go, why not launch your projectile (object under the influence of gravity), and measure how far it goes?

Attempt	Distance (in cm)
1	
2	
3	
4	

We'll make it a little competition amongst all your classmates, so make sure to photograph your catapult (design points will be up for grabs), as well as trying to get a video of your catapult in action.

Be sure to send any photos/videos/ any proof of your work to your teacher to be awarded a score.

Test your knowledge

Energy:

1) After a catapult throws a stone, what is the main type of energy which is applied to the stone during it's flight?

   a) Thermal energy ☐
   b) Kinetic energy ☐
   c) Elastic potential energy ☐
   d) Gravitational potential energy ☐

2) Which of the following quantities is a scalar? (Scalar's do not take direction into account)

   a) Speed ☐
   b) Velocity ☐

3) Can you name two different types of energy which these catapults did not use?

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Projectile Motion:

4) At what angle of release would you expect a catapult to throw a rock at its maximum distance?

______°

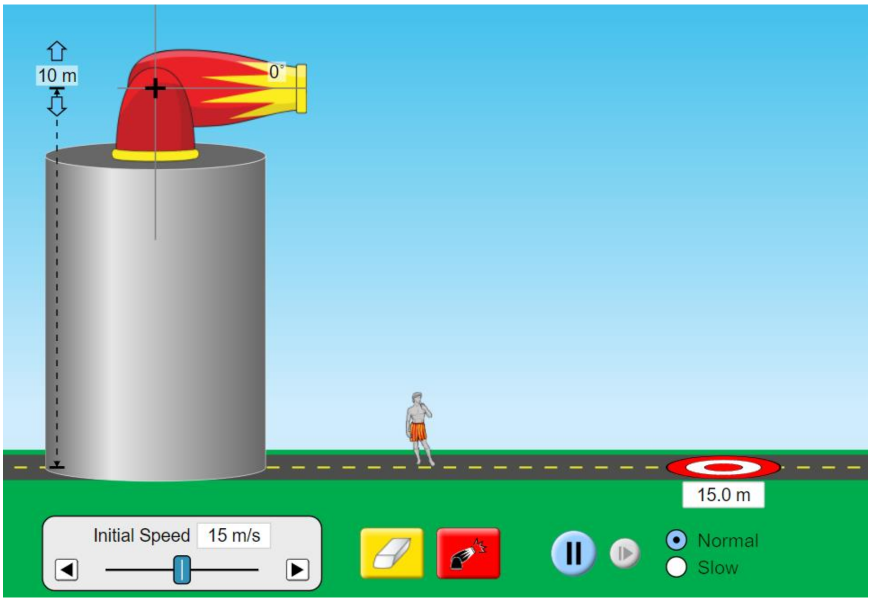
5) At what angle of release would you expect a catapult to throw a rock at its minimum distance?

______°

A little extra

Down below is a link to a projectile motion simulator. Try changing the angle, height and speed of the canon to land the object on the target!

Simulator: https://phet.colorado.edu/en/simulation/projectile-motion



Think about how far your projectiles went when you launched your homemade catapult. Do you think you could have made it go further knowing what you know now?

Competition

If this activity is being run as a competition (check with your teacher to find out) then make sure you do the following things to be in with a chance of winning:

- Submit to you teacher your answers to the questions in the 'test your knowledge section' along with the recorded distances from your catapult testing
- Include one or more pictures of your catapult to show your design, feel free to add in any comments about why you designed it the way you did
- Include a video of your catapult in action so your teacher can see how it works