Activity worksheet: orbits and gravitation

Name	Group	Date

What you will learn

With the orbits simulation you will repeat Newton's thought experiment: firing a cannonball from the top of a mountain faster and faster. You will find out why the Moon and satellites do not fall down, why distant planets take so long to go round the Sun and how two stars that attract each other move.

How to work. Each activity has three steps:

1. **Predict.** Before looking at the simulation, write down what you think will happen and why.
2. **Observe.** Set up the simulation, watch what happens and note down the data.
3. **Explain.** Compare what happened with your prediction and explain why.

If your prediction turns out to be wrong, don't rub it out: getting it wrong and understanding why is the best way to learn.

Each activity has a link that opens the simulation already set up. If you have the worksheet on paper, go to **simulaciencia.es/en/simulations/orbitas** and set it up as described under “Set up the simulation”.

How to read the data. In “Newton's Cannonball”, the “Launch Speed” slider sets the speed of the shot in km/s, and the “Orbital Status” panel gives the speed, the altitude above the ground, the type of trajectory and the period (how long it takes to go round once). The “2×” and “4×” buttons speed up time.

Before you start

What do you think now? Write T (true) or F (false). You will come back to this table at the end.

Statement	T or F
a) Astronauts on the Space Station float because there is no gravity up there.	
b) A satellite needs an engine pushing it forwards so that it does not fall.	
c) If you throw something faster, it lands further away, but it always ends up falling.	
d) The Sun is at the centre of the Earth's orbit.	
e) A planet always moves at the same speed.	
f) When two stars attract each other, the big one stays still and the small one goes round it.	

Activity 1. Newton's cannonball

Set up the simulation: Newton's Cannonball mode with the launch speed at **3.45 km/s**. Open the simulation ready to use

Predict. If you fire the cannonball faster and faster, what do you think will happen? Draw the paths you expect for a slow ball, a fast one and a very fast one.

My prediction (drawing)

Observe. Press "▶ Fire". Then press "↺ Reset", change the speed with the slider and fire again.

Launch speed (km/s)	Does it reach the ground?	Trajectory shown on the panel
3.45		
5.75		
6.90 ("Vc" button)		

Explain.

1. Why does the cannonball fall? Which force pulls on it?
2. At 6.90 km/s the cannonball goes round and round without touching the ground. Has it stopped falling? Open the "Newton's thought experiment" card if you need help.

My answers

Activity 2. A circular orbit

Set up the simulation: Newton's Cannonball with **6.90 km/s** ("Vc" button). Open the simulation ready to use

Predict. During a complete orbit, will the speed and height of the cannonball change? Which forces do you think act on it?

My prediction

Observe. Fire and write down the data in the "Orbital Status" panel at two different points of the orbit.

Moment	Speed (km/s)	Altitude (km)	Period (min)	Orbits
First reading				
Second reading				

Explain.

1. What kind of motion does the cannonball have? What changes and what stays the same?
2. Which force acts on the cannonball? Which way does it point? Is there any force pushing it forwards?

My answers

Activity 3. Faster: ellipses and escape

Set up the simulation: Newton's Cannonball with **8.05 km/s**. Open the simulation ready to use

Predict. Now the cannonball leaves faster than in the circular orbit. What shape will its path have? Will it always travel at the same speed?

My prediction

Observe. Fire, press "4×" and look at the furthest point (apogee, marked in blue) and the closest point (perigee, in yellow). Then try 10.35 km/s.

Launch speed (km/s)	Trajectory	Speed at perigee (km/s)	Speed at apogee (km/s)	Energy ε (km²/s²)
8.05				
10.35		—	—	

Explain.

1. Where does the cannonball travel faster, close to the Earth or far away? Explain it using kinetic and potential energy.
2. What is different about the energy ε when the cannonball escapes? Why does it not come back?

My answers

Activity 4. The planets of the Solar System

Set up the simulation: Solar System mode. Open the simulation ready to use

Predict. Which planet do you think takes longer to go round the Sun: Mercury or Neptune? Why?

My prediction

Observe. The "Planets" list gives the mean distance from the Sun (a, in astronomical units, AU) and the period (T, in years). Click on each planet to see T^2/a^3.

Planet	a (AU)	T (years)	T^2/a^3
Mercury			
Earth			
Mars			
Jupiter			
Neptune			

Explain.

1. How is the distance from the Sun related to the period?
2. What is special about the last column? This is Kepler's third law.

My answers

Activity 5. Kepler's laws

Set up the simulation: Kepler's Laws mode, **1st Law** with eccentricity 0.50. Open the 1st law · Open the 2nd law

Predict. Where is the Sun in a planet's orbit: at the centre or somewhere else? Does the planet move equally fast all the way round?

My prediction

Observe. In the 1st law, move the “Eccentricity (e)” and look at the shape of the orbit and the position of the Sun. Then open the 2nd law and watch the yellow area swept by the Sun–planet line.

Situation	What I observe
e = 0.00	
e = 0.50: where is the Sun?	
e = 0.90	
2nd law: where does the planet go fastest?	
2nd law: what is the swept area like close to and far from the Sun?	

Explain. The Earth's orbit has e = 0.017. Try a similar value (0.02). Is it very stretched? Why should planetary orbits not be drawn as very elongated ellipses?

My explanation

Activity 6. Two stars that attract each other

Set up the simulation: Binary Stars mode with 2.0 and 1.0 solar masses. Open the simulation ready to use

Predict. If one star has twice the mass of the other, which one will move? Around which point will they turn?

My prediction

Observe. Look at the orbits of the two stars and the green cross “CM” (centre of mass). Change the masses.

Star 1 (M☉)	Star 2 (M☉)	Which one has the bigger orbit?	Where is the CM?
2.0	1.0		
3.0	3.0		
5.0	0.5		

Explain.

1. Why do both stars move and not just the small one? Think about Newton's third law.

2. With 5.0 and 0.5 M☉, the big star hardly moves. Why, then, do we say that the Earth goes round the Sun?

My answers

Apply what you have learnt

Solve these without the simulation. Write the law, the calculation with its units and the result. Data: g at the surface = 9.8 m/s², radius of the Earth = 6371 km.

1. Calculate the weight of a 70 kg astronaut on the surface of the Earth and on the Space Station, 400 km up, where g ≈ 8.7 m/s². Is it true that they “weigh nothing” there?
2. A planet takes 8 years to go round the Sun. Using Kepler's third law ($T^2 = a^3$, with T in years and a in AU), calculate its mean distance from the Sun.
3. The cannonball in activity 2 travels round a circle of radius 8388 km in about 128 minutes. Calculate its speed in km/s and compare it with the one on the panel.
4. Explain why the Moon does not fall onto the Earth even though the Earth attracts it.

Problem	Working and result
1	
2	
3	
4	

Review your ideas

Go back to the “Before you start” table. Would you change any of your answers? Write which one and explain why, using something you saw in the simulation.

What has changed in my ideas

Going further (Years 12 and 13)

1. Set the weight equal to the centripetal force, $GMm/r^2 = mv^2/r$, and calculate the speed of the circular orbit for r = 8388 km, with $GM = 3.986 \cdot 10^5$ km³/s². Compare it with the "Vc" button.
2. Check that the escape velocity on the "Ve" button is $\sqrt{2}$ times the circular speed. What sign does the energy ε have just below and just above the escape velocity? Try 9.66 and 9.78 km/s.
3. In "Kepler's Laws", "3rd Law", change the semi-major axis from 0.40 to 1.30 and write down T and T^2/a^3. Does the period change if you only change the eccentricity?

My answers

Self-assessment

Put an X to show how confident you feel at the end.

I can...	Yes	Nearly	Not yet
Explain that the gravity that makes objects fall is what keeps satellites in orbit			
Link the launch speed to the type of trajectory			
Explain why a satellite goes faster close to the Earth			
State and apply Kepler's laws			
Explain that gravitational attraction is mutual			
Use a prediction and an observation to change an idea I had			

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