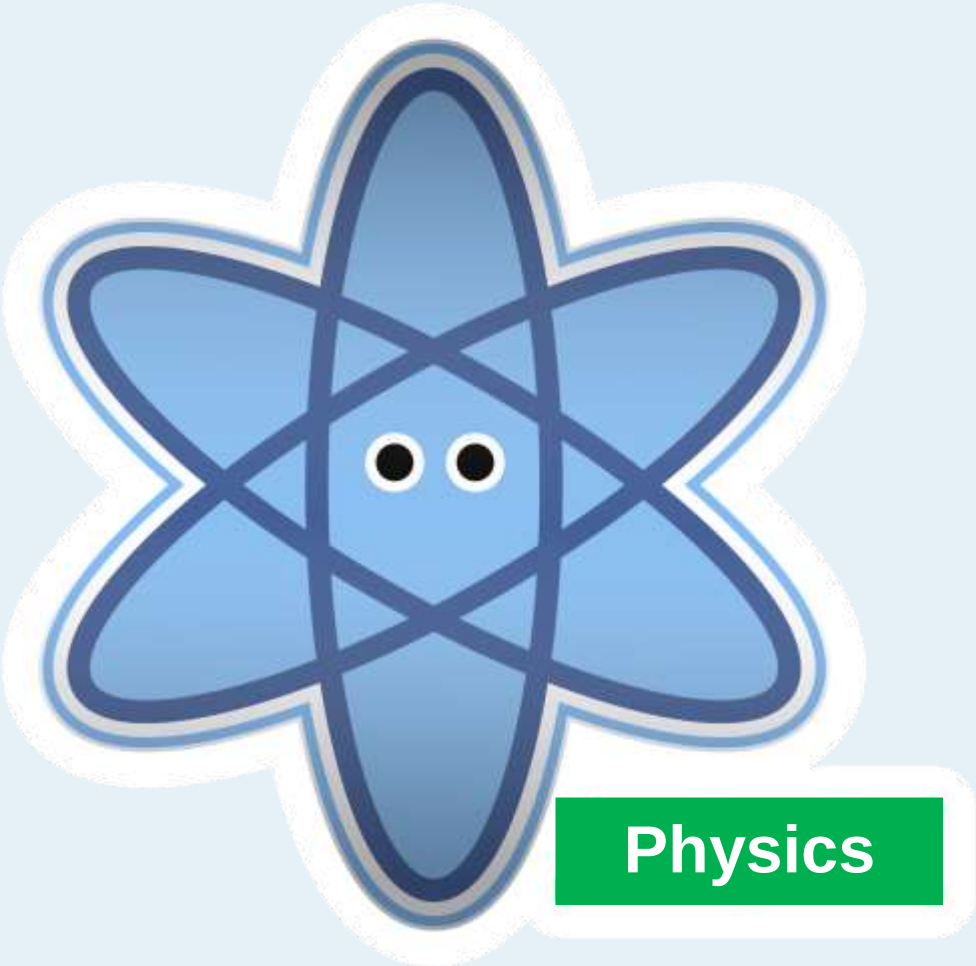


Educational Materials on the Subject

From the Earth to the Moon and Back – Gravitation in the Earth-Moon system

FORM 11

Student Materials

Task 1

Download the app at https://play.google.com/store/apps/details?id=com.ColumbusEye.Main and install it. Attach the printed work sheet showing the earth to the wall at head level. Open the app and direct your smartphone's camera at the worksheet.

a) Take a few steps forward and back while pointing the camera towards the worksheet. The earth, the moon and the distance between the two bodies are implemented true to scale. Determine the scale with the tools at your disposal.

b) Approach the earth with your camera closely. Postulate a theory about what is happening here and why. Compare your theory with other planetary systems in our solar system. Tip: Take a closer look at the orbital time or rather the month length.

Task 2

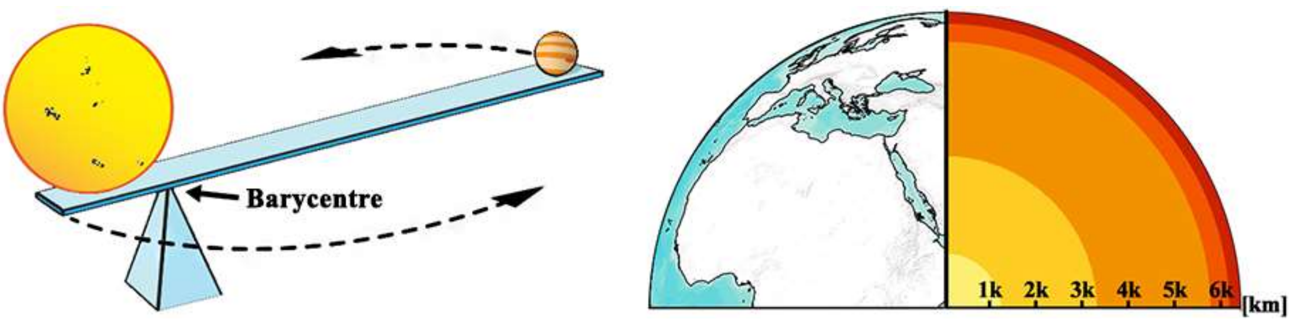
Open the display of the tides (bottom of the screen) and once again take a couple of steps forward and back. What can be observed about the effect of the moon's distance on the tides?

a) Draw a graph with the earth-moon-distance against the deviation of the tidal amplitude and describe it. Try to think of other factors that influence the tidal amplitude.

b) Tides can also be found on the earth's moon and on other moons in our solar system. Discuss the consequences. Keep in mind the resulting forces, such as e.g. friction.

Task 3

On their common orbit around the sun, the earth and the moon revolve around a common centre of gravity or rather barycentre. For the following calculations you are to assume that the masses of the earth and the moon concentrate on one point each.



Marker 1: Representation of the barycentre between a star and its heavy planet (changed according to NASA Spaceplace). Animation: movement of two bodies around a common barycentre (3D: own animation, 2D: changed according to NASA Spaceplace).

a) Calculate the position of the barycentre within the earth with regards to the minimum and the maximum distance between earth and moon and draw them into Marker 1 (right side).

b) Astronomers discuss whether planet-moon systems with a barycentre between the two bodies should be classified as double planets. Calculate the distance between earth and moon at which the barycentre would lie between the two, when the barycentre is moved outside the earth.

c) On its orbit, the moon moves away from the earth an average of 3,8 cm every year. How long will it take until the barycentre is temporarily outside of the earth and how long until it leaves the earth permanently. Which other couples in our solar system are already in that situation?

d) Discuss how a barycentre could be used for the search of exoplanets.

Task 4

Read the information text about the formation of the Earth-Moon system.

a) Compare the effects of the small distance to today's distance with regards to the young earth and…

b) …discuss the effects of a considerably larger distance in the far future.

Task 5

Point your smartphone camera at marker 2 and watch the video (Lunar Eclipse seen from Space). Why does the moon appear so small in comparison to the earth?

Task 6

The shadow of the earth does not reach the moon during every full moon, much like the shadow of the moon does not cause a solar eclipse during every new moon.

a) Try to produce solar eclipses with varying distances between your smartphone moon and the image of the earth. Start at a maximum distance of 100.000 km from earth and slowly move backwards. The app's search aid will help you to find the moon's shadow, should you lose it in the process.

b) Explain the reasons for the different diameters of the moon's shadow on earth and how it can be calculated. (The surface may be assumed as flat for simplification).

c) Compared to the earth's orbit, the moon's is tilted 5°. Explain through calculations, why the shadows of the earth and the moon can miss the other celestial body.

Tables and Formulas

	sun	earth	moon
mass	$1{,}989 \cdot 10^{30}$ kg	$5{,}974 \cdot 10^{24}$ kg	$7{,}349 \cdot 10^{22}$ kg
radius (equator)	696.342 km	6.378 km	1.737 km

Figure 1: the bright side of the moon (source: NASA).

	minimum	maximum
distance earth-moon	356.410 km	406.740 km
distance sun-earth*	147.097.233 km	152.095.566 km

***** varies every year, figures for 2018

barycentre: $r_E = r \cdot \frac{m_M}{m_E+m_M}$ or $r_M = r \cdot \frac{m_E}{m_M+m_E}$

with

r_E : distance earth's centre – barycentre

r : distance earth-moon

r_M : distance moon's centre – barycentre

m_E: mass earth

m_M: mass moon

The Formation of the Earth-Moon system

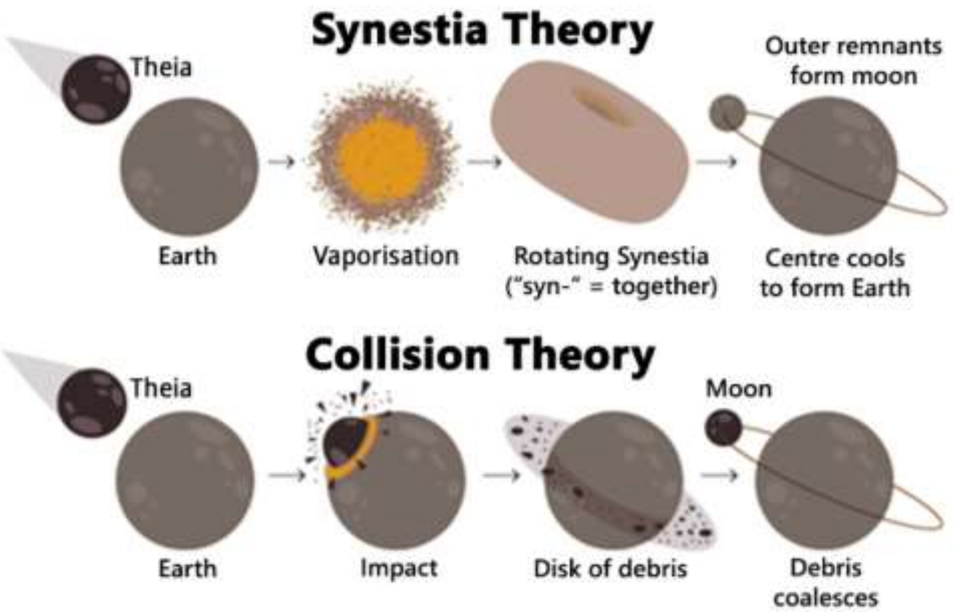
Approx. 4,5 billion years ago, when the sun had just begun to burn, the solar system's order as we know it today had not been established yet. The gas giants were on much closer orbits around the sun and the orbits of some planets crossed the orbits of other planets and massive asteroids. Thus, the earth collided with another protoplanet, Theia, which was as big as Mars. The collision of the two planets, which were revolving around the sun at a speed of 100.000-200.000 km/h, annihilated both celestial bodies and all that was left was a cloud of molten rock. Dense and heavy enough to revolve around a common gravity centre, the debris cloud formed into planet earth and its moon.

A different popular theory states that the two planets merely grazed each other, at which point Theia was absorbed by the earth and the moon supposedly formed from the debris of the two other planets.

After 4,5 billion years the exact process can only be retraced with the help of a model. However, the isotopic composition of the earth and the moon are so similar that they must have had the same original source of material. A strong indication for the formation from a collision is the fact that the moon is getting further away from the earth by 3,8 cm every year. Since earth and moon have formed closely together, the moon was orbiting the earth very closely after it had formed, in a distance of 20.000 to 30.000 km – barely outside the Roche limit, where it would have been torn apart by the earth's gravitation into a ring of debris.

The interaction between the earth's and moon's gravitation causes a tidal friction which gradually slows down the rotation of both celestial bodies. In the beginning, the friction was so high that the moon's rotation was bound to the earth within a few million years, i.e. the moon always directs the same side at the earth.

The earth's rotation is also slowed down, only much slower due to the mass difference between earth and moon (approx. 81:1). In approx. 15 billion years, the earth will also be directing the same side at the moon and the moon will only be visible from one side of the earth – if both will still exist after the sun will have inflated into a red giant in 5 billion years.



Marker 2: Collision Theory and Synestia Theory regarding the formation of the moon (changed according to: Quanta Magazine). Video: Lunar Eclipse seen from Space (source: Columbus Eye).

Further Sources

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