National High School of Computer Science "TUDOR VIANU", Bucharest, 9F grade

Navigation Plan: Earth to Moon

Team name:

We thought Terrigena is the most appropriate name for our team because this is the Latin word for „created out of earth" („earthborn") and it reflects our most essential quality: we were born on Earth and we represent our planet. It also represents the bond between us all, because even if we have different parents, different skin colours and different opinions we are all „terrigenae". Also, it is a very special name to us, because it is a Latin noun, and our heritage is daco-roman.

Spacecraft name:

We chose Bendis to be the spacecraft's name because this was the name of the ancient daco-tracic goddess of Moon. We thought the name Bendis best represents our ancient cultural and historical heritage (daco-roman) and it also suitable for a spacecraft that will reach the Moon.

Launch time and date:

After researching we discovered that on the 21st of July 2009 at 8:17 pm GMT the Moon is at perigee (it is closest to the Earth), at 357464 km from the Earth. We consider the trajectory to be circular and not elliptical, and therefore we estimate the distance between the Moon and the Earth at 357464 km.
Because of this minimum distance, we choose the launch date to be the 21st of July.

Duration of journey:

We want to calculate the duration of the journey more accurately, and by researching we found the formula for calculating how long it takes for a satellite to be transferred from the low Earth's orbit to the low Lunar orbit.(we considered the Lunar trajectory circular, and not elliptical to simplify the mathematical part of the task a little.)

The duration of the journey is: $\Delta t = \frac{\Pi}{2}(R - R1)\sqrt{\frac{R - R1}{2kM}}$ =3.5 days

Where R is the distance from Earth to Moon and R1 is the radius of Earth's low orbit.

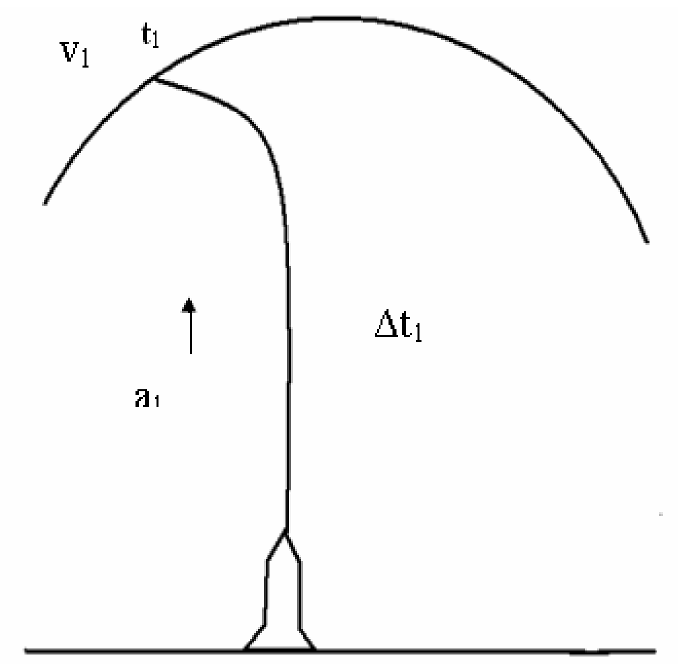
By calculating, we found out that the LCROSS-module will reach the low lunar orbit in 3 and half days.

Expected impact date:

The 24th of July.

Description of route and orbital paths:

Lift off. Entering the orbit



t1=the moment of time when the rocket enters the low-Earth orbit
v1=the first cosmic speed (this is the speed the rocket needs to have at t1, to enter low-Earth's orbit); the speed the rocket has when entering low-Earth's orbit=7.9 km/s
To determine the cosmic speed we used the equations:

$$k \cdot \frac{M \cdot m}{(R+h)^2} = \frac{m \cdot v^2}{(R+h)} \Rightarrow v = \sqrt{\frac{k \cdot M}{R+h}}, \ \mathbf{h \ll R} \Rightarrow$$

$$v_0 = \sqrt{\frac{k \cdot m}{R}}, \quad g_0 = \frac{k \cdot M}{R^2}$$

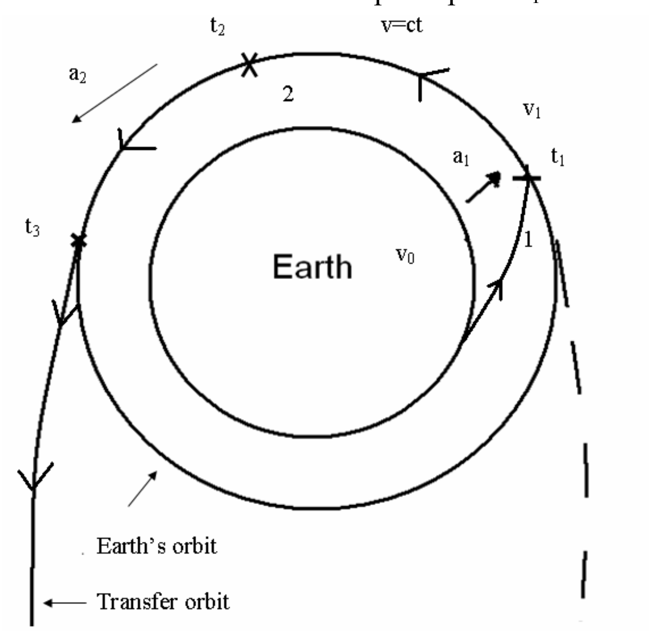
$$v_0 = \sqrt{g_0 \cdot R}$$

The rocket rises accelerating along the trajectory d_1 (the curve is given by the Earth's gravitation) until it enters the Earth's orbit.

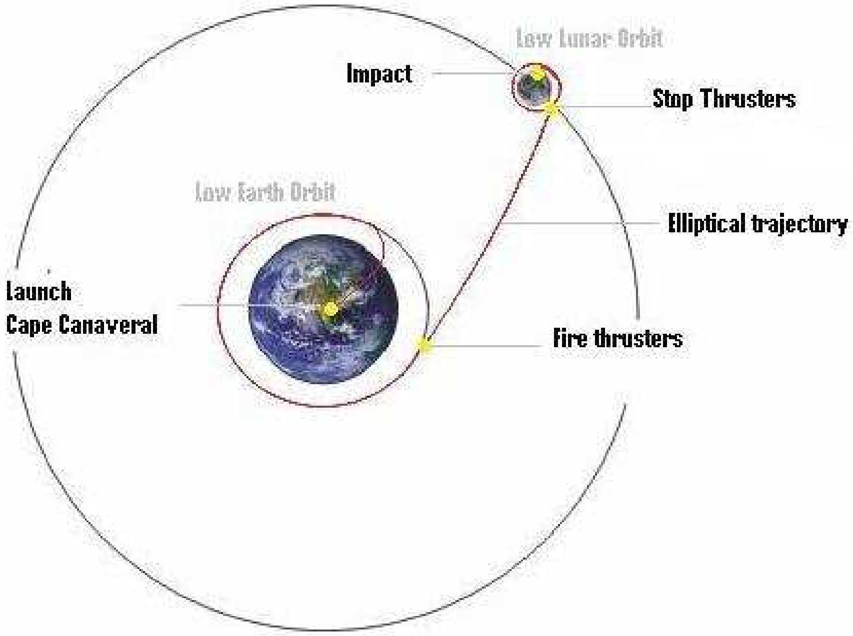
The rocket moves along the trajectory d_2 with the speed v_1 as soon as the engines are stopped, because of the Principle of Inertia, according to which objects tend to maintain their uniform and rectilinear movement as long as other objects/forces do not act upon them, changing this state. In space, friction doesn't exist so the rocket will keep its speed v_1 from the moment when the engines are stopped. The rocket's trajectory is curvilinear (the Earth's orbit), because the Earth's gravity acts upon it.

1. *Stopping the engines after entering Low Earth's Orbit*
2. *Starting to accelerate (t2), until the spacecraft reaches cosmic speed number 2(=11.2 km/s) in order to leave the Earth's orbit (t3).*

The rocket will move accelerating along the trajectory between t2 and t3 (between the “fire thrusters” point and the “neutral gravity point”), from the time t_2 when



the rocket starts its engines again until the time t_3 when they are stopped, in order to have enough force to leave the Earth's orbit using inertia at the time t_3 and to enter the transfer orbit with the speed v_3.



The rocket will move with the constant speed v_3 along the trajectory d_4, from the time t_3, when the engines are stopped, until the moment t_4, because it will not encounter friction and according to the Principle of Inertia, it will keep this speed. The rocket will not keep its rectilinear trajectory because of the Sun's gravity. It will have a curvilinear orientation.

The rocket will fire its thrusters at the time t_4, to enter the Moon's orbit.

$$g_{Moon} = \frac{G_{Earth}}{6}$$

Where *g = the Moon's gravitational acceleration* and
G = the Earth's gravitational acceleration

Once the Moon's orbit is entered, the rocket will orbit until the time t_4 when it reaches the North Pole of the Moon. Here the thrusters will start in order to orientate the rocket towards the North Pole of the Moon.

The day and the time of the launch

Launch date: The spacecraft will be launched when the Moon is at its perigee (the distance between the Moon and the Earth is smallest = 357464 km), this is to say July 22nd. We decided to launch the spacecraft at 10:00 AM or at 2:00 PM, because the time of the launch depends on weather conditions.

Arrival date: July 21st + Δt_f (Δt_f =Δt which we calculated using the transfer orbit formula)

$$\Delta t_f = t_4 - t_0$$

$$\Delta t_f = \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4$$

$$\Delta t_f = \frac{d_1}{v_{1m}} + \frac{d_2}{v_2} + \frac{d_3}{v_{3m}} + \frac{d_4}{v_4} \qquad v_2 = v_1$$

$$\Delta t_f = \frac{d_1}{v_{1m}} + \frac{d_2}{v_1} + \frac{d_3}{v_{3m}} + \frac{d_3}{v_3} \qquad v_4 = v_3$$

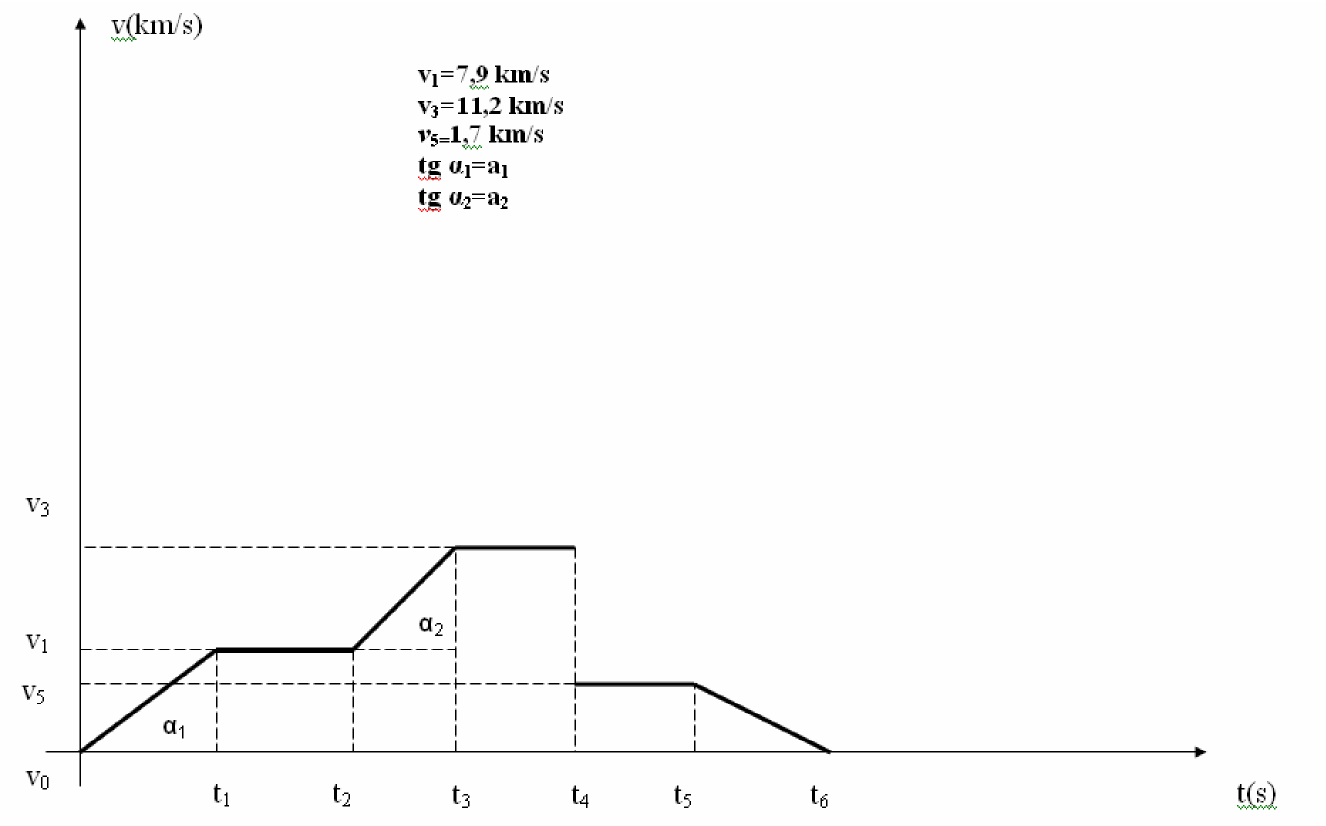
$x = v_l \cdot \Delta t_f$

$x = v_l \ (t_4 + t_0)$

v_l=3100km/h

Speed chart

Assuming that the speed at time t_4 is approximately equal to the speed at time t_3 and the adjustment time of t_4 is negligible compared to the other times => t_4 = moment.

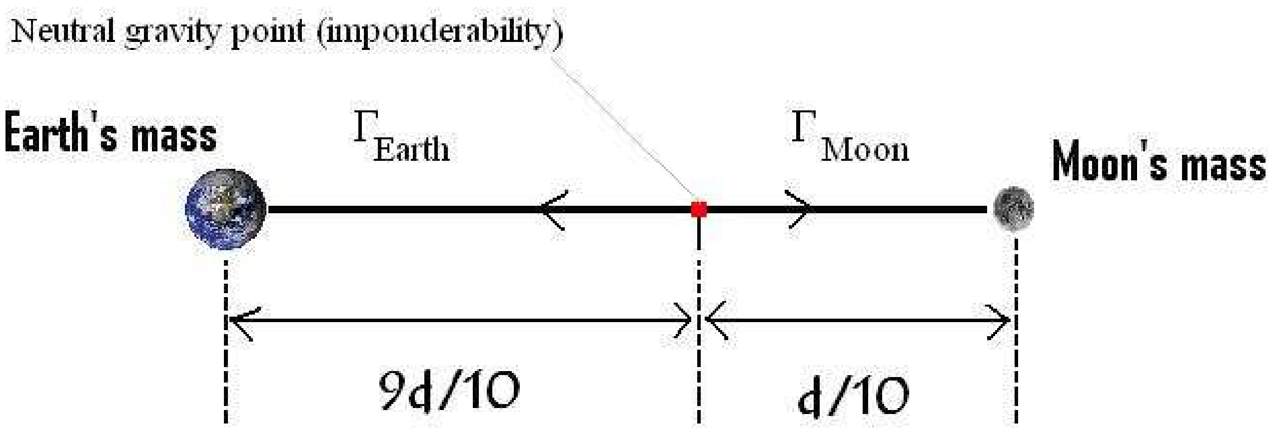


Problem situation: What if Bendis is off course?

We imagined that we are the navigation officers on the LCROSS mission control team and that we have just received new tracking data that says the spacecraft is off course; it will miss its impact point by 10 km. We know that the spacecraft is currently 10 hours from impact on the Moon and there's a final opportunity to perform a correction manoeuvre 2 hours from now. Assuming that the spacecraft weighs 7275 lb and that the total rocket thrust is 10 lb of force, we tried to find out how long we must fire the onboard thrusters so that the spacecraft gets back on target.
First of all, we thought that because the spacecraft is currently 10 hours from impact on the Moon and the final opportunity to perform a correction manoeuvre is 2 hours away from now, the spacecraft must reach its desired impact location in 8 hours.

By researching, we found that 1 lb=4.448222 N.
Therefore, the force of 10 lbs that is applied to the rocket by the thrusters once they are fired is equivalent, in the SI, to 44.48222 N.
The next step is to convert the weight from lb to N. As we know that 1 lb=4.448222 N and that the spacecraft weighs 7275 lb, we calculated that that its weight is 32360.81505 N.
Afterwards we calculated the spacecraft's mass. The general equation is $G = m \cdot g \Rightarrow m = \frac{G}{g} = \frac{32360.81505N}{9.80665\frac{N}{kg}} = 3299.884778kg$.
Now we need to find the acceleration, using the equation $F = m \cdot a \Rightarrow a = \frac{F}{m} = \frac{44.48222N}{3299.884778kg} = 0.01347994$.
We previously found out that $\Delta v = 1.25km/h$. Because we chose to work with SI units, we have to convert km/h to m/s. Therefore, $\Delta v = 1.25 \cdot 1000m/h = 1250m/h = 1250m/3600s = 0.3473m/s$.
Because we know both the acceleration and the velocity, we calculated the amount of time the thrusters must be fired. $v = a \cdot t \Rightarrow t = \frac{v}{a} = \frac{0.3473m/s}{0.01347944m/s^2} = 25.77s$

The neutral gravity point (imponderability point)



By researching, we have found out about a very particular point on the spacecraft's trajectory: the neutral gravity point, where the spacecraft has got no acceleration.
The neutral gravity point is the point on the segment which connects the centres of two celestial bodies considered to be of negligible size reported to the distance between them, in order for any material point that is situated here to remain still.
To calculate the distance between the neutral gravity point to each of the two celestial bodies we will use, first of all for the body with the mass M_1 and secondly for the body with the mass M_2, the formula: $\Gamma_1 = k\frac{M_1}{x^2}$,

where we used x to abbreviate the distance between the centre of the body with the mass M_1 and the neutral gravity point $\Gamma_2 = k\frac{M_2}{(d-x)^2}$, where d is the distance between the centres of the two bodies.

As any object situated in the neutral gravity point has no acceleration, $\Gamma_1 = \Gamma_2$

$$\frac{M_1}{x^2} = \frac{M_2}{(d-x)^2} \Leftrightarrow \frac{M_1}{M_2} = \left(\frac{x}{(d-x)}\right)^2 \Leftrightarrow \sqrt{\frac{M_1}{M_2}} = \frac{x}{d-x} \Leftrightarrow x = d\frac{\sqrt{M_1}}{\sqrt{M_2}+\sqrt{M_1}} = \frac{d}{1+\sqrt{\frac{M_2}{M_1}}}$$

$$= \frac{d}{1+\sqrt{\frac{1}{81}}} = \frac{d}{1+\frac{1}{9}} = \frac{9d}{10}$$

Bendis’ thrusters must be fired after the spacecraft has crossed the neutral gravity point, which, as we calculated, is situated at nine tenths of the distance between the Earth and the Moon.

Because we chose to use a Hohmann type of trajectory (transfer orbit), we thought we should calculate Bendis’ velocity. The jump from one orbit to another represents the transfer of one satellite from the initial radius to the final one, where the initial radius and the final one are different.
The initial velocity of the satellite with the mass M in order for it to stay on the orbit with the radius R_0 is:

$$v = \sqrt{\frac{k \cdot M}{R_0}}$$

The satellite’s final velocity will be: $v = \sqrt{\frac{k \cdot M}{R_1}}$

The satellite’s velocity correction will be: $\Delta v = \sqrt{\frac{k \cdot M}{R_1}}\left(1 - \sqrt{\frac{2R_0}{R_0 + R_1}}\right)$

In this case, the duration of the satellite’s transfer will be: $\Delta t = \frac{\pi}{2}\left|R_0 - R_1\right|\sqrt{\frac{\left|R_0 - R_1\right|}{2kM}}$, which, as we calculated, equals approximately 3 days.

Additional formulas

For the rectilinear uniform movements, the laws of motion are the following:

$a=0$

$v=ct$

$x = x_0 + v_0 \cdot t$

For the varied uniform rectilinear movement, the laws of motion are the following:

$$a=ct$$

$$v = v_0 + a(t - t_0)$$

$$x = x_0 + v_0(t - t_0) + \frac{a}{2}(t - t_0)^2$$

The movement around the Earth is effectuated with v=constant in module, under the force of the Earth’s attraction (circular uniform motion).

Navigation Instruments:

Because we cannot guide the LCROSS module from Earth we will use an Inertial Navigation System (INS). This will allow us to know the position, orientation and velocity of the spacecraft at any moment. We’ll need the following instruments:

1. Accelerometers, which measure the linear acceleration of the system in the inertial reference frame, which works on the same principle as the passenger that is pressed back into his seat as the acceleration increases and is pulled forward as the acceleration decreases.
2. Gyroscopes, which measure the angular velocity of the system in the inertial reference frame.

We also thought that we might need a radar system, infrared radiometers, infrared lasers, charge-coupled devices, magnetospheric imaging instruments, polarimeters, photometers, plasma detectors, very long baseline interferometers, infrared lasers.

The advantages of the INS alone are huge: the INS requires initialization (it will be initialized before the launch), but after initialization, it doesn’t require any more external data.

Methods of guidance, navigation, control, and tracking:

We thought about several guidance, navigation, control and tracking methods.
We found out that a navigation system is made out of three major sub-sections: inputs, processing, and outputs. The input section includes sensors, course data, radio and satellite links, and other information sources. First of all, we will use the INS as the input section, because it allows us to track the Bendis Spacecraft and it also measures the spacecraft’s velocity, orientation and position.
Then there is the processing section, composed of one or more Central Processing Units, which integrates this data and determines what actions, if there are any, are necessary to maintain or achieve a proper direction in which the ship is moving. We thought that if we can’t control the spacecraft from Earth we need to create a program that leads Bendis. On one hand, to create this kind of program we need very advanced technology that can measure everything up to the tiniest units of measurement: the INS. The program must detect if something goes wrong with the spacecraft, by correlating the data provided by the INS with Bendis’ trajectory map. It will have all the situations where something went wrong with the spacecraft and its trajectory in its memory, implemented by the programmer.

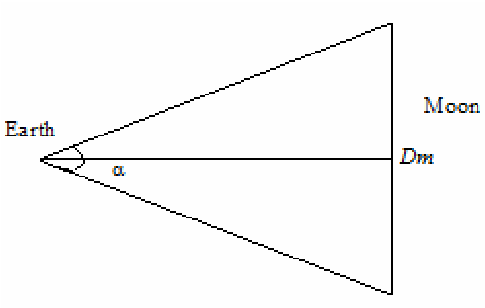
Then, using the data provided by the INS and the information stored in its memory, it will be able to calculate which thrusters to fire or how to modify Bendis' speed, in order to place the spacecraft on its right trajectory.
The information is then transmitted to the outputs which fire the proper engines and modify the spacecraft's course according to the information received from the CPU.
Also, we thought that it might be useful if the spacecraft had all kinds of sensitive sensors to heat, light, speed of air, volume of gas etc.

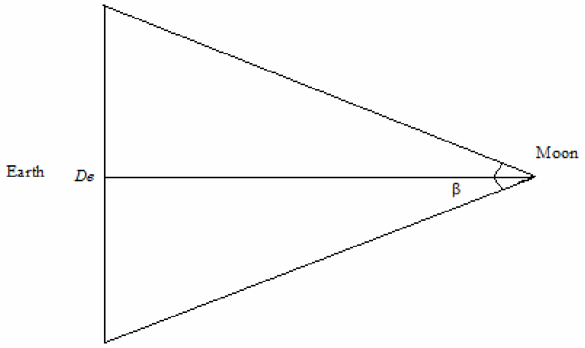
We discovered…

Challenge Question #1:

Astronomers measure the apparent size of celestial objects using degrees. Just as a circle contains 360 degrees, you can see what one degree on the sky looks like by slicing the horizon into 360 slices.

From Earth, the moon's apparent diameter is half a degree. What is the apparent diameter of the Earth as seen from the moon?





In the first image we drew the angle (α) of the Moon seen from the Earth, and in the second one the angle (β) of the Earth seen from the Moon.

$$\tan\frac{\alpha}{2} = \frac{\frac{Dm}{2}}{dEM} \Leftrightarrow \frac{Dm}{2dEM} \quad \alpha<6° \Rightarrow \frac{\alpha}{2} = \frac{Dm}{2dEM} \quad (1)$$

$$\tan\frac{\beta}{2} = \frac{\frac{De}{2}}{dEM} \Leftrightarrow \frac{De}{2dEM} \quad \beta<6° \Rightarrow \frac{\beta}{2} = \frac{De}{2dEM} \quad (2)$$

From (1) and (2) => $\dfrac{\frac{\alpha}{2}}{\frac{\beta}{2}} = \dfrac{\frac{Dm}{2dEM}}{\frac{De}{2dEM}} \Leftrightarrow \dfrac{\alpha}{\beta} = \dfrac{Dm}{De} \Rightarrow \beta = \alpha\dfrac{De}{Dm}$

Where Dm is the Moon's diameter (1738 km);
De is the Earth's diameter (6378 km);
dEM is the distance from Earth to Moon;
$\alpha = 0.5° = 0.0088$ rad

So $\beta = 0.0088\dfrac{6378}{1738} = 0.032$ rad $= 1.837°$

Challenge Question #2:

Look at the moon and notice that there are two different kinds of terrain: bright areas and dark areas.

- **How are they different, besides their colour?**

The dark areas differ from the bright ones by composition, formation, altitude, position and age (and therefore are dichotomous).

- **What are the compositions (rock types) of the bright and dark areas of the moon?**

The dark areas are composed of basaltic lava[volcanic igneous rocks] containing fine-grained basaltic rock, sometimes glass-like, volatile-depleted which is rich in Fe, Mg, Ti and also contains Al and K.

The bright areas are composed of anorthosites(a rock type with anorthite as a dominant mineral which is a Ca-rich plagioclase feldspar) and impact breccias(conglomerates of shattered rocks cemented together), having low abundances of Fe, Ti and other heavy elements compared to the dark side.

- **What are the Latin words scientists use to refer to these areas, and what do they mean?**

Carolus Linnaeus started this system of categorization in the 1700s, using Latin and Greek, since those were the languages used for science.
The Latin word scientists use to refer to the dark areas is "maria" (singular "mare") , which is the Latin for "seas", since ancient astronomers believed this dark surfaces were filled with water.
The Latin word used by scientists to refer to the bright areas on the Moon is "terrae", which is the Latin for "ground", or "earth".

Challenge Question #3:

How old are the oldest rocks found on the moon?

The oldest rocks on the Moon are anorthosites, which are composed almost entirely of plagioclase feldspar. They appeared soon after the Moon was formed, when the feldspar crystallized and floated to the top of a global magma ocean that surrounded the Moon. The magma ocean ought to have solidified about 4.55 billion years ago. One possibility is that the young ages reflect the impact ages and not the original time of igneous crystallization. Some other old lunar rocks are basalts, which date back to 3.3 billion years , anorthosites(for example specimen 60025 which was collected by Apollo 16) which are 4.2 billion years old, (that is much older than the lunar basalts).

How old are the oldest rocks found on the Earth?

The oldest rocks found so far on Earth date from the Archean Eon; they are zircons found in Western Australia which are 4.36 billion years old, the "faux amphibolite" found at the Nuvvuagittuq greenstone belt which are from 3.8 to 4.28 billion years old, the Acasta Gneisses (a rock outcrop of Archean tonalite gneiss found in the Slave Crater in Northwest Territories, Canada which is 4.03 billion years old) , the Isua Supracrustal rocks (found at the Isua greenstone belt and which are 3.7 to 3.8 billion years old) and some of the rocks found on the eastern shore of Canada's Hudson Bay which are around 4.28 billion years old. Some other old Earth rocks are found in the Minnesota River Valley and northern Michigan (3.5-3.7 billion years), in Swaziland (3.4-3.5 billion years) and in Western Australia (3.4-3.6 billion years).

Why don't we find rock on the Earth as old as those on the moon?

Earth is different from the Moon in many ways, but one of the most important is geology. Earth is the only terrestrial world with a fully developed system of plate tectonics, which keeps its continents in perpetual motion and continually regenerates the planet's crust.

Although tectonics builds mountains, the processes of erosion are constantly at work wearing them back down to nothing.

The rocks on Earth's surface are under the constant attack of tectonical movements, magmatism, volcanism, weathering (produced by the variations of temperature, the freezing of the water and the melting of the ice in the fissures of the rocks, the penetration and growth of plant roots in the rock's fissures), chemical alteration, chemical attack (some organisms produce chemicals that help dissolve rocks) and erosion (produced by running water, glaciers and wind).

The Moon stopped having tectonic activity a very long time ago and hasn't got any atmosphere(which is the main condition for chemical alteration, chemical attack, weathering and erosion to exist), so the only thing that may destroy rocks on Moon's surface is the impact of a meteorite with its surface.

Because the lunar rocks are not exposed to any kind of transformation, they haven't changed too much since the Moon was formed. The rocks on Earth have suffered many transformations and therefore very little of the rocks that initially formed Earth's surface remained intact.

Challenge Question #4:

a. Why don't we see the far side of the moon from Earth?

The Moon is slightly lopsided, so when it started rotating on its axis the Earth's gravity tugged a little more on the more massive side. Over time, because of the gravitational forces that slowed the rotation, the rotation slowed to the point where the bigger side was always facing the earth. So, every time the moon orbits around the earth, it turns once on its axis, and the far side is never visible. The amount of time it takes the Moon to make a complete orbit around the Earth matches the amount of time it takes the Earth to complete one rotation. In both cases, this is 27 days 7 hours and 12 minutes, and for this reason Moon keeps always the same position towards the Earth.

b. Explain the difference between the far side and the dark side.

People commonly confuse the term "dark side" with "far side" when referring to the different hemispheres of the Moon. The moon does have a dark side. It is the hemisphere that is turned away from the Sun. The location of the dark side changes constantly, moving with the terminator, the dividing line between sunlight and dark. The far side is the hemisphere that is permanently turned away from the Earth. The far hemisphere was first photographed in 1959 by the Soviet Luna 3 probe and was first directly observed by human eyes in 1968, when the Apollo 8 mission orbited the Moon. Surprisingly, the rough and battered surface of the far side looks very different from the near side which is covered with smooth dark lunar "maria". The likely explanation is that the far side crust is thicker, making it harder for molten material from the interior to flow to the surface and form the smooth "maria". It includes the largest known impact feature in the Solar System: the South Pole - Aitkin basin.

However, dark side of the moon is the same with the far side of the moon only during a full moon, because from Earth the far side is never seen, the side that can be seen is the near side which is also the light side during a full moon.

Challenge Question #5:

a) For an early lunar expedition with 4 people staying on the lunar surface for 8 days, how much does it cost to carry enough water for the crew's stay on the lunar surface?

1 pound……100 000 $

$$1 \text{ astronaut} \begin{cases} 0.8 \text{ gallons} * 4 \text{ days} \\ 1.2 \text{ gallons} * 4 \text{ days} \end{cases} \Rightarrow 1 \text{ astronaut} \ldots 8 \text{ gallons/8 days} \Rightarrow$$

4 astronauts….32 gallons/8 days

After researching, we found out that a quantity of water expressed in gallons is equal in pounds to the number of gallons of the water * 8.33. => 32 gallons = 8.33 * 32 = 266.56 pounds.

266.50 pounds * 100 000 $\frac{\$}{pound}$ =26 656 000 $

b) For a lunar base crew of 6 people, living on the moon for 180 days, how much does it cost to supply the base with enough water, carried from Earth, for that crew?

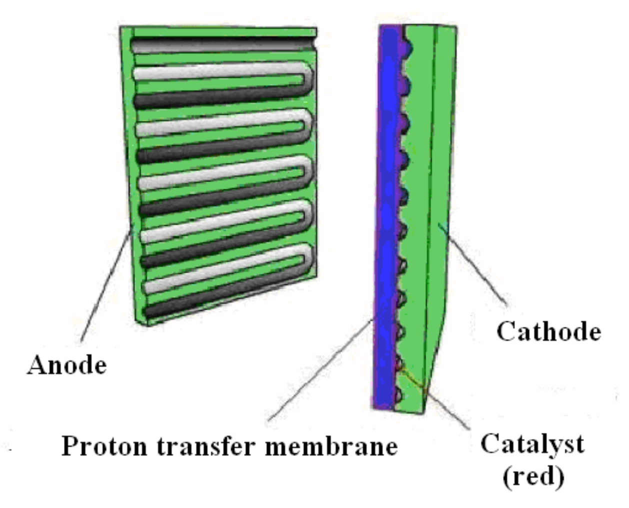
1 astronaut on the Moon drinks as an average 1 gallon of water/day=>6 astronauts drink 6 gallons of water/day=>during the 180 days mission, 1080 gallons of water will be drank=> 8996.4 pounds of water will be drank => it will cost 899 640 000 $ to transport this quantity of water from the Earth to the Moon.

c) To save the cost of transporting water from Earth, suggest one way that astronauts on the moon might obtain water locally, assuming there is NOT any ice buried under the surface.

We have thought about several methods:

1. Installing an atmospheric water generator in the spacecraft before launch; this device draws water from the natural humidity in the air produced by breathing, sweat-evaporation etc, collects it and then purifies it so that it can be drank. We searched information about such devices and we found out that as an average, a dehumidifier produces between 10 and 20 litres of water per day. This device works on electricity, so solar panels on the spacecraft could provide the device enough electricity.
2. carrying hydrogen and oxygen instead of water, which are far less heavy than water; due to the electric energy provided by the solar panels on the spacecraft, some molecules of hydrogen should react with molecules of oxygen (the reaction should take place in a special tank) and form water, but also propulse the spacecraft with the high amount of energy that comes out of this reaction (572 kJ). –we wrote about this method below, in detail-
3. carrying aqua vapours(which are less heavy than water in liquid state) into a tank-the aqua vapours are obtained through the distillation of water/reverse osmosis; at the arrival on the Moon the reverse process of distillation should take place in order to obtain pure water.
4. Recycling the water produced by the astronauts' bodies.

What we need for the reaction of water production: the fuel cell with the polymer membrane.
The way this methods works:



The **anode**, the negative electrode of the fuel cell, guides the electrons which provide the hydrogen molecules so they can be used in the external circuit. It has engraved channels inside it to disperse the hydrogen gas equally over the catalyst's surface.
This is the reaction from the fuel cell, at the anode:
$2H_2 \Rightarrow 4H^+ + 4e^-$

The **cathode**, the positive electron of the fuel file has engraved channels inside it to distribute the oxygen on the catalyst's surface: it leads the electrons back into the

external circuit to the catalyst, where it can recombine with the hydrogen and oxygen ions, forming water.
The reaction at the cathode:
$O_2 + 4H^+ + 4e^- => 2H_2O$

The electrolyte is the **proton transfer membrane,** which blocks electrons. The **catalyst** is a special material which facilitates the reaction between oxygen and hydrogen. It is usually made of platinum nanoparticles which cover a piece of paper or carbon rag.

Global reaction:
$2H_2 + O_2 => 2H_2O$

The chemical part in the process of obtaining water would be that H_2 enters the fuel cell on the anode's side, where it is forced towards the catalyst by the pressure, the H_2 molecules come in contact with the platinum from the catalyst, it divides them into two H^+ ions and two electrons (e^-). The electrons are lead through the anode, where they make their way to the exterior circuit (producing *useful mechanical work*, spinning a motor) and they return to the cathode's part of the fuel cell.
In the cathode's part of the fuel cell, O_2 is forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a powerful negative charge; therefore it attracts the two H^+ ions through ions through the membrane, where it combines itself with an oxygen atom and two of the electrons from the exterior circuit to form water molecules.

Challenge Question #6:

a. *Scientists have estimated that the total area of the moon that is permanently in shadow, at both north and south poles, is 12,500 square kilometres. Based on the above assumptions, how many gallons of water are contained in the lunar Polar Regions?*

We calculated how many gallons of water are contained in the lunar polar regions below, using the following abbreviations:

g = gravitational acceleration
m_1 = lunar soil mass
m_2 = ice mass
V_1 = lunar soil volume

V_2 = ice volume
ρ_1 = density of lunar soil = 2.9 g/cm^3
ρ_2 = density of water $\approx$ 1000 kg/m^3
A = area of the part of the moon in shadow = 12500 km^2
h = the depth of soil in which ice exists = 2 m

$$V_1 = \frac{m_1}{\rho_1}$$
$$V_1 = A \cdot h;$$

$$m_1 = A \cdot h \cdot \rho_1;$$
$$m_2 \cdot g = m_1 \cdot g \cdot \frac{2}{100}$$
$$m_2 = m_1 \cdot \frac{2}{100} = \frac{2 \cdot A \cdot h \cdot \rho_1}{100}$$
$$\rho_2 = \frac{m_2}{V_2} \Rightarrow V_2 = \frac{m_2}{\rho_2} \Rightarrow V_2 = \frac{2 \cdot A \cdot h \cdot \rho_1}{100\rho_2} = \frac{2 \cdot 125 \cdot 10^8 m^2 \cdot 2m \cdot 2900 kg/m^3}{100 \cdot 1000 kg/m^3} = 145 \cdot 10^7 m^3$$
$$V_2 = 145 \cdot 10^{10} dm^3 = 145 \cdot 10^{10} L$$

1 gallon…………3.78541178 L
x gallons………..V_2
$$x = \frac{145 \cdot 10^{10}}{3.78541178} = 383,049,476,324.079 \approx 383,000,000,000 \text{ Gallons}$$

b. Based on the information in Question 5, how many astronauts, living and working at bases on the moon, could this much water sustain for a year?

Based on the answer from question a, there are approximately 383,000,000,000 gallons of water in the lunar soil.
1 gallon of water…1 astronaut…1 day (as we demonstrated in the previous LCROSS question)
365 gallons of water….1astronaut….365 days

$\Rightarrow$ 383,000,000,000 Gallons of water…approximately 1,000,000,000 astronauts…365 days $\Rightarrow$ the water on the Moon could sustain approximately 1,000,000,000 astronauts for a year.

c. Do you think it is realistic to harvest all this water? Suggest ways to help astronauts working at a base in the moon’s Polar Regions to obtain ice from lunar soil. Estimate how much water could be harvested in one year of base operations.

Firstly, in order to conclude if it’s realistic to harvest the water/ice on the Moon, we have thought about the advantages and disadvantages of harvesting all this water. We think that the key elements determining whether harvesting all this water is realistic or not are the costs and the method’s efficiency.
On one hand, transporting water from Earth is very expensive, as we have previously found out. On the other hand, harvesting water from the lunar soil requires tanks, curved mirrors and/or a special device that first needs to be designed and assembled and then transported to the Moon. In order for this device to work it needs power or fuel. Since the ice to be harvested exists only in the lunar soil from the permanently shadowed craters, the harvesting device could not be powered by photo-voltaic modules, unless the sunlight is redirected towards the ice-harvesting device using curved mirrors, for example. Therefore, fuel should be transported or sunlight should be redirected – using curved mirrors, for example. The cost of transporting fuel or these big

curved mirrors would add to the cost of designing, building and transporting the ice harvester.
Moreover, the water obtained by the harvester should be, first of all, analyzed and afterwards, purified.
The spacecraft should also transport a small quantity of water for the astronauts to use during the flight to the Moon.
Overall, the main costs of the harvesting project would be determined by the cost of transporting the curved mirrors, the tanks, the harvesting device and 10-20 gallons of water, depending on the number of astronauts on the spacecraft, for the astronauts to use during the flight to the Moon. Because all these are less heavy than the water necessary to the astronauts during their mission, it would cost less to transport the harvesting project equipment.
Moreover, we found out by calculating (details on bottom off page number three) that by harvesting the ice/water in the lunar soil the astronauts would collect approximately 145,000 g of water per day, which indicates that water/ice- harvesting would be an efficient method.
Furthermore, the water on the Moon could be used in future missions as fuel for spacecraft, once it has been decomposed into hydrogen and oxygen atoms.
As a conclusion, we think that harvesting water on the Moon - not all the water on the Moon, because we should not consume all these water resources at once - is a realistic and viable project.

Secondly, we came up with a number of suggestions meant to help astronauts in obtaining water from the lunar soil.

1. Astronauts could heat the lunar soil to 100-200 Celsius degrees, because at this temperature the ice in the soil would melt and evaporate. The vapours could be collected in special tanks.
2. Astronauts could use an Ice-harvesting device powered by photo-voltaic panels.
3. Astronauts could heat the lunar soil to 800 Celsius degrees, because at this temperature the oxygen and the hydrogen in the soil would be released. The oxygen and hydrogen atoms would be stored in a special tank and held in the proper conditions so that the reaction between them takes place. The energy resulted from the reaction of water production could be used in heating the soil.
4. Astronauts could heat the soil to 10-20 Celsius degrees, using focused sunlight and then use a well for extracting the melted ice from the soil.
5. Astronauts could use a device to transform the sunlight into high-frequency microwaves which would be shot into the lunar soil; this would make the ice in the lunar soil go through a sublimation process. The resulting vapours would be stored in a tank.

All the methods listed above, except number 3, require water purification after it has been harvested.

Thirdly, we estimated that the water-harvesting operation cannot take place more than five times a day, and never on more than 500,000 cm^3 of lunar soil.

500,000 cm^3 of lunar soil ….at a time $\Rightarrow$ 2,500,000 cm^3 of lunar soil…….1 day

2.9 g of lunar soil in 1 cm^3 of lunar soil $\Rightarrow$ 7,250,000 g of lunar soil in 2,500,000 cm^3 of lunar soil

2% of the lunar soil is represented by water $\Rightarrow$ there are 145,000 g of water in the 2,500,000 cm^3 of lunar soil processed during one day of ice/water-harvesting.

$V=\frac{m}{\rho}$, therefore, because the density of water is $1000 kg/m^3$, there are $0.145\ m^3$ of ice in the lunar soil processed during one day of ice-harvesting.

There are 1000 litres in $1\ m^3$. Therefore, there are 145 litres of ice/water in the lunar soil processed during one day of ice-harvesting.
1 litter = 0.264172052637296 gallons $\Rightarrow$ 145 litres = 38.30494763240792 $\approx$ 38.3 gallons of water $\Rightarrow$ during one year of base operations approximately 13979.5 gallons of water could be harvested.