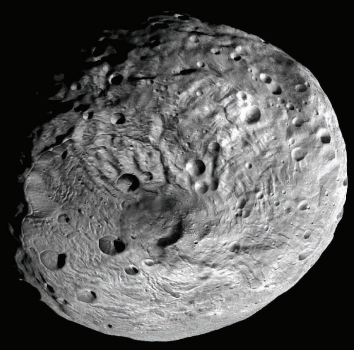
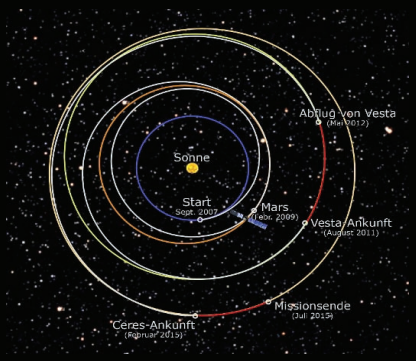
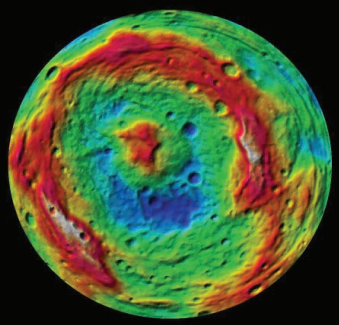
National Aeronautics and Space Administration

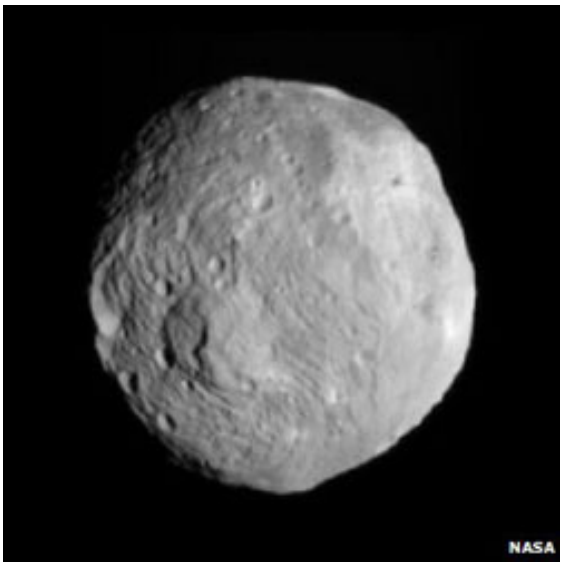
Mission Math I







NASA's Dawn spacecraft arrived at asteroid Vesta in July 2011 after a 2000-day spiral journey from Earth. Since arrival, Dawn has taken numerous images of the Vesta to map its surface features. This image, taken from a distance of 41,000 kilometers, shows the nearly-spherical shape of this cratered asteroid at a resolution of 3.8 km/pixel. The width of the image is about 740 kilometers.



Problem 1 – With the help of a millimeter ruler, what is the scale of this image in km/mm?

Problem 2 – By making measurements of 5 different 'diameters' of this asteroid, what is the average diameter of the asteroid based upon this particular view of its shape?

Problem 3 – Approximate the shape of this asteroid as a sphere. What is its volume in cubic kilometers based on the average diameter you computed in Problem 2.

Problem 4 - The density of this asteroid is estimated to be about 3700 kilograms per cubic meter, similar to crustal rocks on Earth. What is the mass of this asteroid in millions of metric tons (megatons)?

Problem 1 – With the help of a millimeter ruler, what is the scale of this image in km/mm?

Answer: The width of the image, if the page is printed normally, is about 74 millimeters, which corresponds to the stated 740 kilometers, so the scale is 740/74 = **10 kilometers/mm.**

Problem 2 – By making measurements of 5 different 'diameters' of this asteroid, what is the average diameter of the asteroid based upon this particular view of its shape?

Answer: An example of 5 diameter measurements is 52, 51, 54, 54 and 53 millimeters for an average value of 52.8 millimeters. Converting this to kilometers we get **528 kilometers as the average diameter.**

Problem 3 – Approximate the shape of this asteroid as a sphere. What is its volume in cubic kilometers based on the average diameter you computed in Problem 2.

Answer: The volume of a sphere is $V = 4/3\ \pi R^3$, so

$V = 1.333(3.141)(528/2)^3$

$\mathbf{V = 7.7 \times 10^7\ km^3}$

Problem 4 - The density of this asteroid is estimated to be about 3700 kilograms per cubic meter, similar to crustal rocks on Earth. What is the mass of this asteroid in millions of metric tons (megatons)?

Mass = Density x Volume.

$= 3700\ kg/m^3 \times 7.7 \times 10^7\ km^3 \times (1000\ meters/1km)^3$

$= 2.8 \times 10^{20}$ kg

In millions of metric tons:

Mass = 2.8×10^{20} kg x (1 ton/1000 kg) x (1megatons/1,000,000 tons)

= **28 billion megatons**

$$Fg = \frac{GMm}{r^2}$$

$$Fc = \frac{mV^2}{r}$$

NASA's Dawn satellite entered orbit around the asteroid Vesta in July, 2011. An important method of determining the mass of an astronomical body is by using a satellite orbiting the body in a circular orbit, where the gravitational force, Fg, from the primary body exactly equals the centrifugal force, Fc, due to the satellite's orbital motion. These forces are given by the equations to the left.

M = mass of primary body
M = mass of satellite
R = radius of satellite orbit
V = circular speed of the satellite
G = Newtonian constant of gravity

Problem 1 - When you set these two equations equal to each other, representing the balance of the two forces acting on the satellite, what happens to the mass of the satellite?

Problem 2 – What is the equation for the mass of the primary body, M, in terms of the other physical quantities?

Problem 3 – If the satellite makes one complete orbit in a time interval equal to T, what is the formula for the average circular velocity of the satellite?

Problem 4 – Using your answer to Problem 3, re-write and simplify the equation in Problem 2 so that M is only in terms of G, R and T.

Problem 5 – If G = 6.6 x 10^{-11} m^3 sec^{-2} kg^{-1} and the units for M, T and R are kilograms, seconds and meters, what is the mass of asteroid Vesta, in megatons, if the orbital radius of the Dawn spacecraft R= 725 kilometers, and the satellite period T = 4.1 hours?

Problem 1 - When you set these two equations equal to each other, representing the balance of the two forces acting on the satellite, what happens to the mass of the satellite?

Answer: **The mass of the satellite. M, cancels, so the remaining variables are independent of the satellite mass.**

Problem 2 – What is the equation for the mass of the primary body, M, in terms of the other physical quantities?

V2/R = GM/R2 so M = V2 R/G

Problem 3 – If the satellite makes one complete orbit in a time interval equal to T, what is the formula for the average circular velocity of the satellite?

$V = 2\pi R/T$

Problem 4 – Using your answer to Problem 3, re-write and simplify the equation in Problem 2 so that M is only in terms of G, R and T.

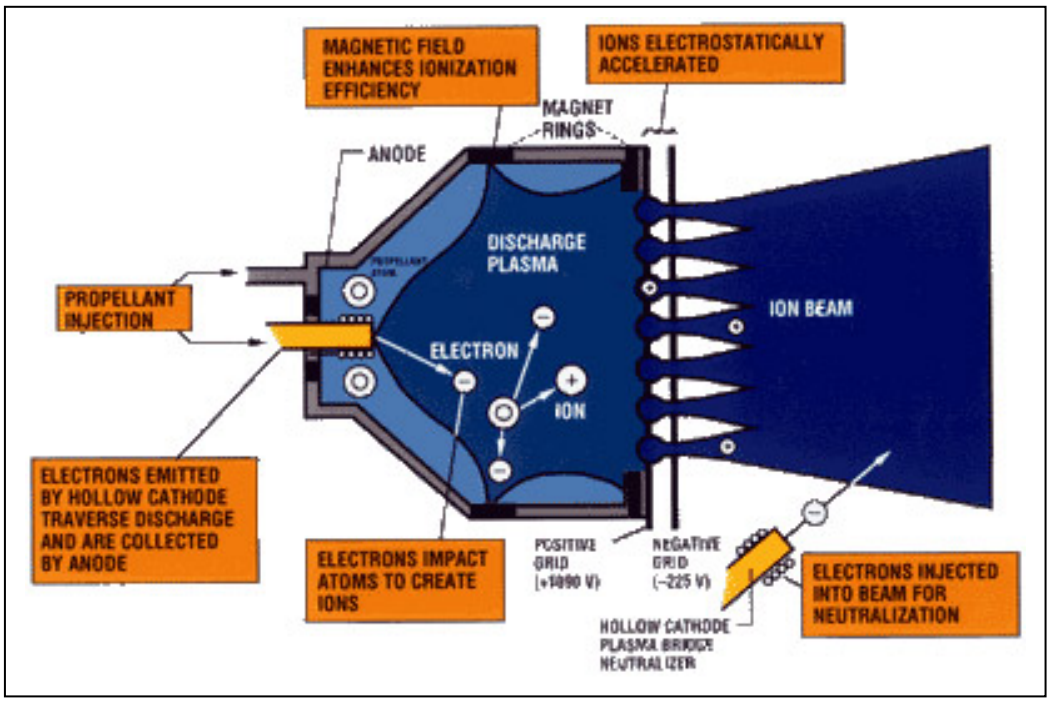
M = (2pR/t)2 R/G so M = 4p2 R3/GT2

Problem 5 – If $G = 6.67 \times 10^{-11}$ m^3 sec^{-2} kg^{-1} and the units for M, T and R are kilograms, seconds and meters, what is the mass of asteroid Vesta if the orbital radius of the Dawn spacecraft R= 725 kilometers, and its period T = 4.1 hours?

R = 725 km = 725,000 meters
T = 4.1 hours x 3600 sec/1hr = 14760 seconds

M = 4 (3.141)2 (725000)3 / (6.67×10^{-11})(14760sec)2
= 1.0×10^{21} kgs

1 megaton = 10^9 kg, so **M = 100 billion megatons**.



NASA's Dawn spacecraft does not use ordinary rocket engines to travel interplanetary distances, but instead uses the new Ion Engine technology developed decades ago, and widely used in commercial satellites for station-keeping in orbit. Ion engines eject streams of charged xenon atoms at tens of thousands of kilometers per second. The gentle push provided by the ionized exhaust produces the acceleration needed for interplanetary journeys. Unlike chemical rockets, ion engines can remain on for thousands of hour, or days, at a time so that very high speeds build up over time.

Problem 1 – The Dawn ion engine ejects about 3.25 milligrams of xenon atoms every second, and at launch, the spacecraft was provided with a fuel supply of about 471 kilograms of xenon. At the sustained emission rate, how many days can the ion engines continue to provide thrust for the spacecraft?

Problem 2 – The spacecraft initially had a total mass of 1218 kilograms of which 471 kilograms was fuel.

A) Write a linear equation that gives the total remaining mass of the spacecraft as a function of the elapsed time in days for the interval T = [0,1600] if the fuel mass loss rate is 3.25 milligrams/sec.

B) After how many days will the spacecraft total mass equal 900 kilograms?

Problem 1 – The Dawn ion engine ejects about 3.25 milligrams of xenon atoms every second, and at launch, the spacecraft was provided with a fuel supply of about 471 kilograms of xenon. At the sustained emission rate, how many days can the ion engines continue to provide thrust for the spacecraft?

Answer: Time = Mass / rate
= 471,000 grams / 0.00325 grams/sec
= 145 million seconds.
= 145 million sec x (1 day/24 hours) x (1 hour/3600 seconds)
= **1678 days.**

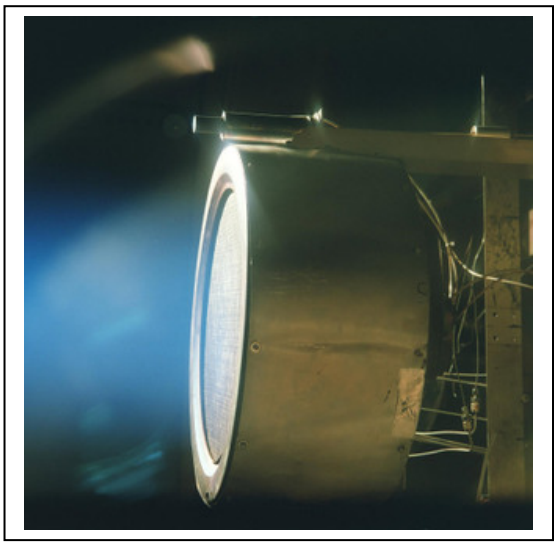
Problem 2 – The spacecraft initially had a total mass of 1218 kilograms of which 471 kilograms was fuel. A) Write a linear equation that gives the total remaining mass of the spacecraft as a function of the elapsed time in days for the interval T = [0,1600] if the fuel mass loss rate is 3.25 milligrams/sec. B) After how many days will the spacecraft total mass equal 900 kilograms?

Answer: In 1 day, the spacecraft loses 0.00325 grams x 24h x 3600 sec/hr = 281 grams or 0.281 kilograms.

The spacecraft non-fuel mass is 1218 – 471 = 747 kg, so the equation is
M(T) = 747 kg + [471 kg – 0.281 kg/day x T(days)]

A) **M(T) = 1218 – 0.281 T kilograms**.

B) 900 kg = 1218 – 0.281T so T = 318/0.281 so **T = 1132 days**.



According to elementary physics, F = m x a where F is the force measured in Newtons, m is the mass of a body measured in kilograms, and a is the resulting acceleration of the body in meters/sec^2.

The Dawn spacecraft uses three ion engines to travel from Earth to distant asteroids in the solar system. The total force (called thrust) of the ion engines is only F = 270 milliNewtons, but this constant thrust can be maintained for hundreds and even thousands of days at a time.

The 1218-kg, Dawn spacecraft was inserted into its interplanetary trajectory to rendezvous with the asteroid Vesta in 2011. After launch and entry into Earth orbit, the ion engines were then turned on for the duration of the journey. During its trip to the asteroid Vesta, the total mass of the spacecraft declined as the initial 471-kg fuel was ejected by the ion engines.

Problem 1 – If the formula for the mass of the spacecraft is given by M(T) = 1218 – 0.281 T kilograms, where T is in days, how many days will it take for the 471-kg fuel supply to be reduced to zero if it is lost at the rate indicated by the equation?

Problem 2 - What is the formula for the acceleration of the spacecraft, a(T)?

Problem 3 – After 1000 days,

A) What is the total mass of the spacecraft and

B) What is the acceleration of the spacecraft?

Problem 1 – If the formula for the mass of the spacecraft is given by M(T) = 1218 – 0.281 T kilograms, where T is in days, how many days will it take for the 471-kg fuel supply to be reduced to zero if it is lost at the rate indicated by the equation?

Answer: The rate is determined by the slope of the linear equation so R = -0.281 kg/day and then

$$T = \frac{471kg}{0.281kg/day}$$ so T = **1676 days**

Problem 2 –What is the formula for the acceleration of the spacecraft, a(T)?

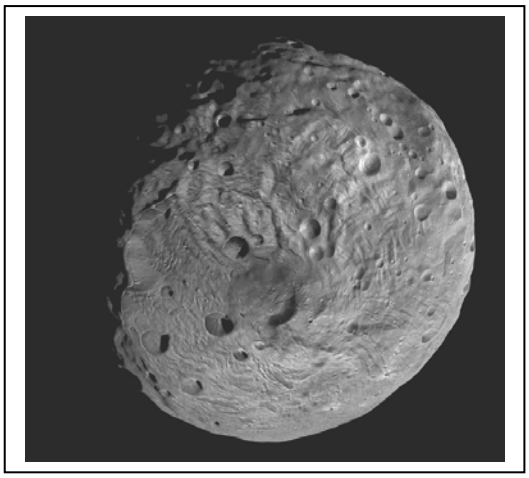
Answer: Since F=ma and F = 0.270 Newtons, a = F/M so

$$a(T) = \frac{0.270}{1218 - 0.281T}$$ **meters/sec^2**

Problem 3 – After 1000 days, A) what is the total mass of the spacecraft and B) what is the acceleration of the spacecraft?

Answer: M(1000d) = 1218 – 0.281(1000) = 1218-281 = **937 kilograms**.

Acceleration = 0.270 Newtons/937 kg = **0.00029 meters/sec^2**.



NASA's Dawn spacecraft contains many instruments to study the surfaces and compositions of distant asteroids. The workhorse instrument is the Framing Camera, which will take all of the high-resolution images of the asteroids it will encounter.

The field-of-view of the camera is 5.5^o x 5.5^o and the electronic camera is similar to the digital camera you use to take pictures. It has a total of 1 million pixels in a square 1024x1024 pixel format.

Although the angular resolution of a camera pixel, θ, is fixed by the camera optics, the linear resolution, L, depends on how far, D, from an object the camera is located according to the formula

$$\theta = 206265 \frac{L}{D}$$

where L and D are in meters and θ is in arcseconds. There are 3600 arcseconds in one degree.

Problem 1 – What is the angular resolution, θ, of one of the image pixels in arcseconds?

Problem 2 – The above image was taken on July 24, 2011 at a time when the Dawn spacecraft was located 5,200 km from the surface of Vesta. What is the smallest feature, L, in meters that the camera can resolve from this altitude?

Problem 3 – Dawn will be observing Vesta from three orbital altitudes: Survey Orbit = 2700 km, the High Altitude Mapping Orbit (HAMO) = 950 km and the Low Altitude Mapping Orbit (LAMO) = 460 km. What are the linear pixel resolutions for the images made at each of these orbits in terms of meters per pixel?

Problem 1 – What is the angular resolution, θ, of one of the image pixels in arcseconds?

Answer: 5.5 degrees = 1024 pixels, so
19800 arcseconds = 1024 pixels then

θ = 19800 arcseconds / 1024 pixels
= **19.3 arcseconds**.

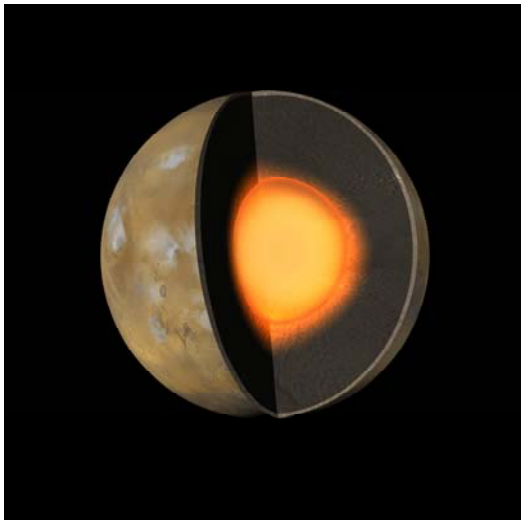
Problem 2 – The above image was taken on July 24, 2011 at a time when the Dawn spacecraft was located 5,200 km from the surface of Vesta. What is the smallest feature, L, in meters that the camera can resolve from this altitude?

Answer: θ = 19.3 arcseconds and D = 5200000 meters, so **L = 486 meters** (or about 0.5 kilometers).

Problem 3 – Dawn will be observing Vesta from three orbital altitudes: Survey Orbit = 2700 km, the High Altitude Mapping Orbit (HAMO) = 950 km and the Low Altitude Mapping Orbit (LAMO) = 460 km. What are the linear pixel resolutions for the images made at each of these orbits in terms of meters per pixel?

Answer: Survey, D = 2700 km so L = **253 meters**
HAMO, D = 950 km, so L = **88 meters**
LAMO, D = 460 km, so L = **43 meters**.

A Simple Model for the Interior of Vesta



A simple model of the interior of Mars
(Courtesy : NASA/JPL)

It is not possible to drill down through the interior of asteroid Vesta to figure out what it is like, but we can create mathematical models that try to predict what the interior may be like. There are some basic things we know about Vesta. It is approximately spherical with an average radius of 253 kilometers. Orbital studies of the Dawn spacecraft suggest a total mass of 259 billion billion kilograms. The average density is 3800 kg/m^3, while detailed spectral studies of its surface suggests basaltic rock indicating lava flows with a density of about 3400 kg/m^3. The deep interior, under pressure from the overlying layers may have a density near 7900 kg/m^3.

One of the simplest models for the interiors of astronomical bodies is to consider a spherical core region surrounded by a concentric mantle shell. Observations establish the total mass and radius of the combined core-mantle model, and the assumed densities for the core and mantle can then be used to estimate the radius of the spherical core.

Problem 1 – From the total mass and radius of Vesta, verify that the average density of this asteroid is about 3800 kg/m^3.

Problem 2 – Create a model that consists of a spherical core with a density of 7900 kg/m^3 and a radius Rc, surrounded by a mantle with a density of 3400 kg/m^3 so that the total mass of each component is equal to Vesta's mass and radius. What value for Rc is consistent with such a simple core-mantle model?

Problem 3 – What percentage of the radius of Vesta may be occupied by the high-density core region in this simple model?

Problem 1 – From the total mass and radius of Vesta, verify that the average density of this asteroid is about 3800 kg/m^3.

Volume of a sphere, $V = 4/3\ \pi\ R^3$ so for Vesta
$V = 1.333 \times 3.141 \times (253{,}000 \text{ meters})^3$
$= 1.7 \times 10^{16}$ meter^3

Density = Mass/Volume
$= 2.59\text{x}10^{20}$ kg / $6.8\ \text{x}10^{16}$ m^3
$= 3800$ kg/m^3.

Problem 2 – Create a model that consists of a spherical core with a density of 7900 kg/m**3** and a radius Rc, surrounded by a mantle with a density of 3400 kg/m^3 so that the total mass of each component is equal to Vesta's mass and radius. What value for Rc is consistent with such a simple core-mantle model?

Answer: The core has a mass of $Mc = 7900 \times 4/3\ \pi\ Rc^3$
The mantle has a volume of $4/3\ \pi\ (R^3 - Rc^3)$
And a mass of $Mm = 3400 \times 4/3\pi\ (R^3 - Rc^3)$

The total mass is then:

$M = 4/3\ \pi\ (3400\ R^3 + 7900\ Rc^3 - 3400\ Rc^3)$ or

$M = 4/3\ \pi\ (3400\ R^3 + 4500\ Rc^3)$

For R = 253 km or 253000 m, and $M = 2.59\text{x}10^{20}$ kg we can solve for Rc:

$2.59\text{x}10^{20}\ \text{kg} = 4/3\ \pi\ (3400\ R^3 + 4500\ Rc^3)$

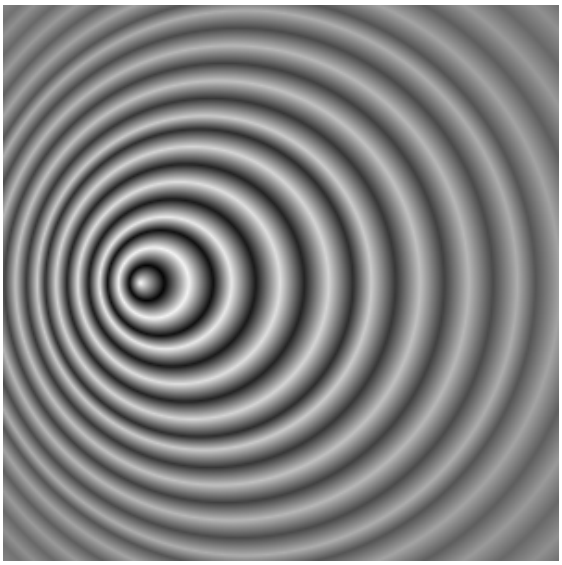
$6.2 \times 10^{19} = 3400\ (253000)^3 + 4500\ Rc^3$

$6.9 \times 10^{18} = 4500\ Rc^3$

Rc = 114 km.

Problem 3 – What percentage of the radius of Vesta may be occupied by the high-density core region in this simple model?

Answer: P = 100% x (114/253) or **45%**.



The observer is located to the left, with a radio source approaching from the right. The wavelengths are compressed in the direction of motion leading to a signal at a higher-frequency.

The NASA, Dawn spacecraft is orbited the asteroid Vesta in 2011. From its Low-Altitude Mapping Orbit (LAMO) with an altitude of 460 km, its orbit period was 4.1 hours. During this time, it periodically radioed data to Earth at an X-band frequency of about 9 gigaHertz (cycles per second).

Because of the Doppler effect, the frequency of the received signals constantly changed as the satellite orbited the asteroid. The Doppler formula is given by

$$V = \frac{f_o - f}{f_o} C$$

Where f_o is the frequency of the signal at the Dawn spacecraft, f is the received frequency at Earth, C is the speed of light, and V is the velocity of the Dawn spacecraft relative to Earth.

Problem 1 – If the radius of Vesta is about 253 kilometers, what is the circular speed of Vesta in its orbit in meters/sec?

Problem 2 – Using the Doppler formula, and with C = 3.0×10^8 meters/sec for the speed of light, what will be the frequency change (fo – f) at Earth of the transmitted signal if the satellite is moving towards Earth at the time of transmission?

Problem 1 – If the radius of Vesta is about 253 kilometers, what is the circular speed of Vesta in its orbit in meters/sec?

Answer: The circumference traveled is

$C = 2\pi (253 + 460)$

$= 4479$ kilometers or 4.8×10^6 meters.

The time taken is T = 4.1 hours x (3600 sec/1hr) = 14760 seconds.

The speed is V = 4.8×10^6 meters / 14760 seconds so **V = 325.2 meters/sec**.

Problem 2 – Using the Doppler formula, and with C = 3.0×10^8 meters/sec for the speed of light, what will be the frequency change (fo-f) at Earth of the transmitted signal if the satellite is moving towards Earth at the time of transmission?

Answer: $V = (fo - f)\, C / fo$

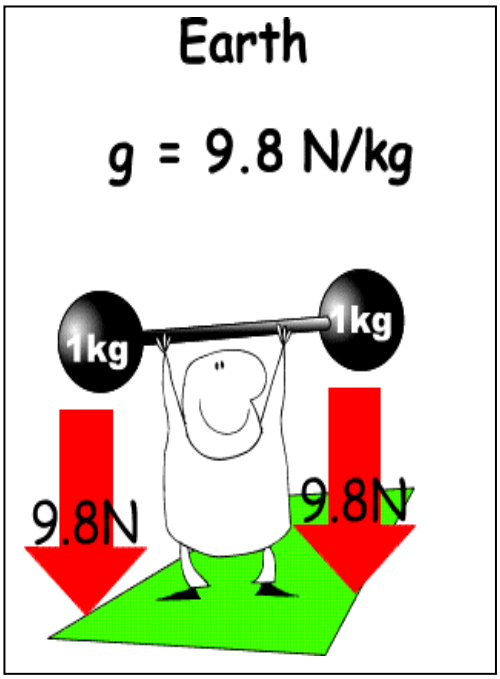
V = 325.2 meters/sec C = 3×10^8 m/s, fo = 9×10^9 Hertz, then

$325.2 = (fo - f)(3.0 \times 10^8)/9 \times 10^9$

9756 Hertz = fo – f

So the frequency change from 9.0 GigaHertz is only **9756 Hertz** or 1 part in 1 million.

The Acceleration of Gravity on Vesta



The Earth is a very large planet, whose mass produces the force of gravity that we feel every day on its surface. This force can be measured by the acceleration it produces, which for motion near Earth's surface, amounts to 9.8 meters/sec^2. Bodies in the solar system that have less mass, and that are smaller than Earth, have a weaker gravity at their surfaces.

The basic formula for acceleration at a planetary surface is just $a = \frac{GM}{R^2}$

where M is the mass of the planet in kilograms, and R is the radius of the planet in meters.

Problem 1 – For the asteroid Vesta, R = 253 km and M = 2.59x10^{20} kg. If the constant of gravity, G = 6.67 x 10^{-11} m^3 sec^{-2} kg^{-1}, what is the acceleration of gravity on the surface of Vesta in meters/sec^2?

Problem 2 – If an astronaut weighs 170 pounds (762 Newtons) on the surface of Earth, how much would they weigh on the surface of Vesta?

Problem 3 – The escape velocity, V, in meters/sec is defined by the equation

$$V = \sqrt{\frac{2GM}{R}}$$

What is the escape velocity from the surface of Vesta?

Problem 4 – In baseball, a fast ball can be pitched at a speed of 100 miles/hr. If 1 mile = 1.6 kilometers, can an astronaut throw a ball fast enough to escape Vesta?

Problem 1 – For the asteroid Vesta, R = 253 km and M = 2.59×10^{20} kg. If the constant of gravity, G = 6.67×10^{-11} m^3 sec^{-2} kg^{-1} , what is the acceleration of gravity on the surface of Vesta in meters/sec^2?

Answer: a = $6.67 \times 10^{-11} (2.59 \times 10^{20})/(253000)^2$
A = 0.27 meters/sec^2.

Problem 2 – If an astronaut weighs 170 pounds (762 Newtons) on the surface of Earth, how much would they weigh on the surface of Vesta?

Answer: The acceleration of gravity is 0.27/980 = 0.00028 of Earth, so the weight would be reduced to this level as well, so 170 pounds / 980 = Weight /0.27 so **Weight = 0.047 pounds** (or 0.7 ounces).

Problem 3 – Answer:

$$V = \sqrt{\frac{2(6.6x10^{-11})(2.59x10^{20})}{253,000}}$$

V = 370 meters/sec.

Problem 4 – In baseball, a fast ball can be pitched at a speed of 100 miles/hr. If 1 mile = 1.6 kilometers, can an astronaut throw a ball fast enough to escape Vesta?

Answer:
Speed = 100 miles/hr x (1.6 km/1 mile) x (1000 meters/1 km) x (1 hour / 3600 sec)
Speed = 44 meters/sec.

No, the escape velocity is still too high for an astronaut to 'toss' a ball into orbit.

The Surface Temperature of Vesta

The temperature of a planet without an atmosphere is determined by the amount of solar energy striking each square-meter of its daytime surface, and the infrared 'heat' energy emitted by the planetary surface back into space. A simple equation that estimates surface temperatures at various distances from our sun, D, and for various surface reflectivities, A, is:

$$T = 284\left(\frac{(1-A)}{D^2}\right)^{\frac{1}{4}}$$

For Earth, located 1.0 Astronomical Units from the sun, D = 1.0. Its surface reflects 40% of the solar energy reaching its surface, so A = 0.4, then T = 250 Kelvins.

Problem 1 - The asteroid Vesta orbits at distances from 2.57 AU to 2.15 AU from the sun. What is the range in temperature for Vesta if its surface has an earth-like reflectivity of A = 0.4?

Problem 2 - The Dawn VIR instrument measured an average temperature of about 167 K. If the asteroid was at a distance of 337 million km, and 1 AU = 149 million km, what was the estimated reflectivity of Vesta at this time?

Problem 1 - The asteroid Vesta orbits at distances from 2.57 AU to 2.15 AU from the sun. What is the range in temperature for Vesta if its surface has an earth-like reflectivity of A = 0.4?

Answer: $T = 284\left(\frac{(1-0.4)}{D^2}\right)^{\frac{1}{4}}$

T = $250/D^{1/2}$

For D = 2.57, **T = 156K** For D = 2.15, **T = 170 K**

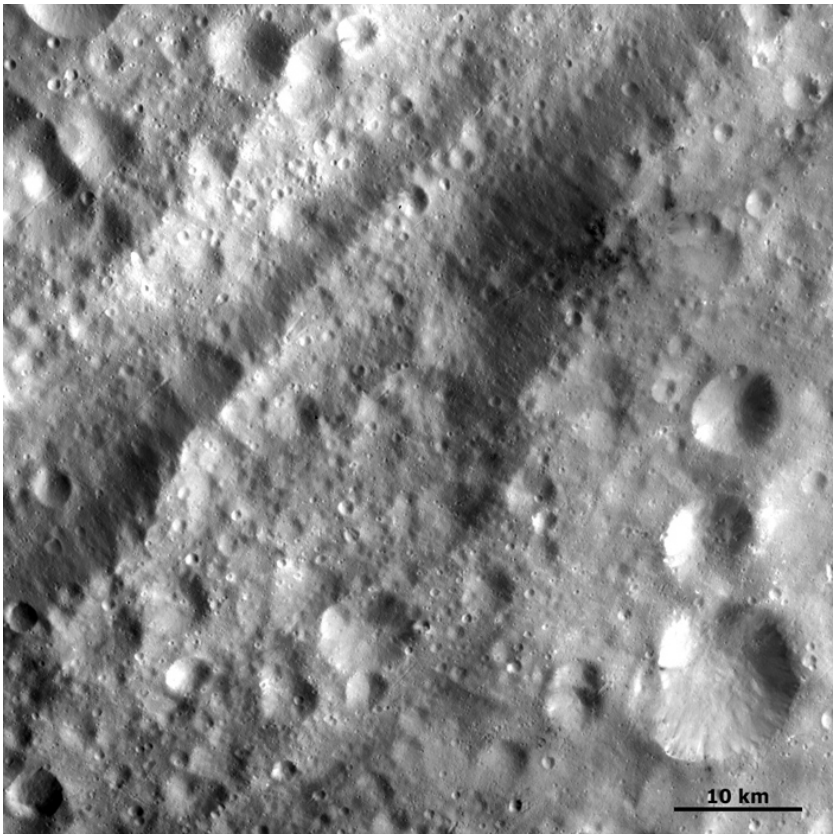
Problem 2 - The Dawn VIR instrument measured an average temperature of about 167 K. If the asteroid was at a distance of 337 million km, and 1 AU = 149 million km, what was the estimated reflectivity of Vesta at this time?

Answer: D = 337/149 = 2.3 AU

Then: $167 = 284\left(\frac{(1-A)}{2.3^2}\right)^{\frac{1}{4}}$ then $0.89 = (1-A)^{\frac{1}{4}}$

So **A = 0.37**, which makes the reflectivity of Vesta, without oceans and polar ice caps, comparable to Earth!

The Cratered Surface of Vesta



This photograph was taken on September 20, 2011 by NASA's Dawn spacecraft. It shows the cratered equatorial region of the asteroid Vesta.

When taking the image, the Dawn spacecraft was at an altitude of 673 kilometers above the surface of the asteroid. The resolution of the photograph is about 66 meters per pixel.

Counting craters according to their diameters is a method astronomers use to estimate the ages of various bodies in the solar system.

Problem 1 – From the available information in the image, determine the scale of the image in kilometers/millimeter using a metric ruler.

Problem 2 – A thorough cratering study would identify all of the circular craters in the image, measure their diameters, and create a frequency 'histogram' showing the number of craters found within various size ranges. For this problem, select 20 craters at random and measure their diameters in millimeters, then convert the measurement to kilometers.

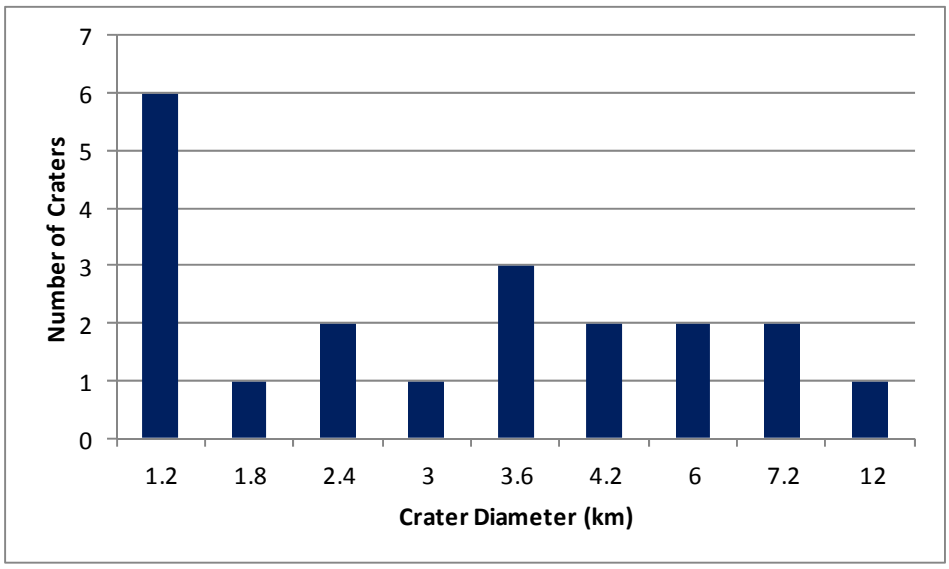
Problem 3 – From the measured crater diameters, create a bar graph showing the frequency of craters in each bin. Convert the measured diameters to kilometers.

Problem 1 – From the available information in the image, determine the scale of the image in kilometers/millimeter using a metric ruler. Answer: Measure the length of the '10 km' bar in millimeters. Reasonable answers are near 17 mm, then S = 10 km/17 mm = **0.6 km/mm**.

Problem 2 – A thorough cratering study would identify all of the circular craters in the image, measure their diameters, and create a frequency 'histogram' showing the number of craters found within various size ranges. For this problem, select 20 craters at random and measure their diameters in millimeters. Answer: Students can use a method that allows them to randomly pick a crater in the picture, such as putting their finger on the picture without looking and selecting the crater closest to where they pointed. We will use this method as an example. The crater diameters found this way are: **20mm, 7mm, 10mm, 2mm, 2mm, 2mm, 10mm, 2mm, 6mm, 4mm, 7mm, 12mm, 4mm, 2mm, 3mm, 12mm, 5mm, 6mm, 2mm, 6mm.**

Problem 3 – From the measured crater diameters create a bar graph showing the frequency of craters in each bin. Convert the measured diameters to kilometers. Answer:

Number	Diameter (mm)	Bin Size(km)
6	2	1.2
1	3	1.8
2	4	2.4
1	5	3.0
3	6	3.6
2	7	4.2
2	10	6.0
2	12	7.2
1	20	12.0



Note that there seems to be a sharp decrease in the number of craters larger than about 1.8 km.

Dawn Spacecraft sees Asteroid Vesta Up Close!

On July 15, 2011 the NASA spacecraft Dawn completed a 2.8 billion kilometer journey taking four years, and went into orbit around the asteroid Vesta. Vesta is the second largest asteroid in the Asteroid Belt. Its diameter is 530 kilometers. After one year in orbit, it will depart in 2012 for an encounter with asteroid Ceres. Meanwhile, from its orbit around Vesta, it will map the surface and see features less than 1 kilometer across.

Problem 1 - Use a millimeter ruler and the diameter information for this asteroid to determine the scale of this image in kilometers per millimeter.

Problem 2 - What is the diameter of the largest and smallest features that you can see in this image?

Problem 3 - Based on the distance traveled, and the time taken by the Dawn satellite, what was the speed of this spacecraft in A) kilometers per year? B) kilometers per hour?

Problem 4 - The Space Shuttle traveled at a speed of 28,000 km/hr in its orbit around Earth. How many times faster that the Shuttle does the Dawn spacecraft travel?

Problem 1 - Use a millimeter ruler and the diameter information for this asteroid to determine the scale of this image in kilometers per millimeter.

Answer: When printed using a standard printer, the width of the asteroid is about 123 millimeters. Since the true diameter of the asteroid is 530 km, the scale is then S = 530 km / 123 mm = **4.3 kilometers per millimeter**.

Problem 2 - What is the diameter of the largest and smallest features that you can see in this image?

Answer: **Students can find a number of small features in the image that are about 1 mm across, so that is about 4.3 kilometers. Among the largest features are the 9 large craters located along the middle region of Vesta from left to right. Their diameters are about 4 to 7 millimeters or 17 to 30 kilometers across. The large depression located in the upper left quadrant of the image is about 40 mm long and 15 mm wide in projection, which is equivalent to 172 km x 65 km in size.**

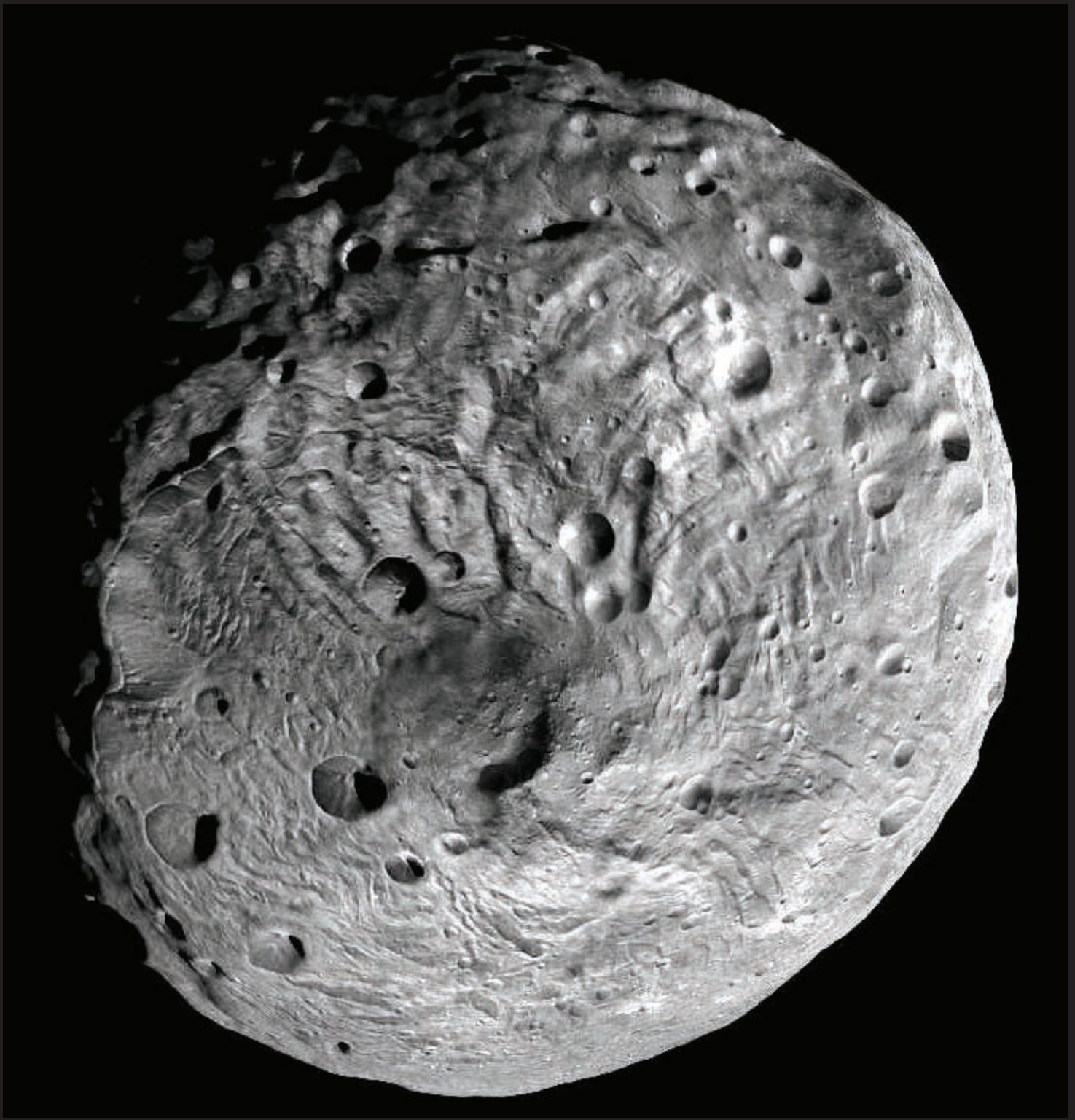
Problem 3 - Based on the distance traveled, and the time taken by the Dawn satellite, what was the speed of this spacecraft in A) kilometers per year? B) kilometers per hour?

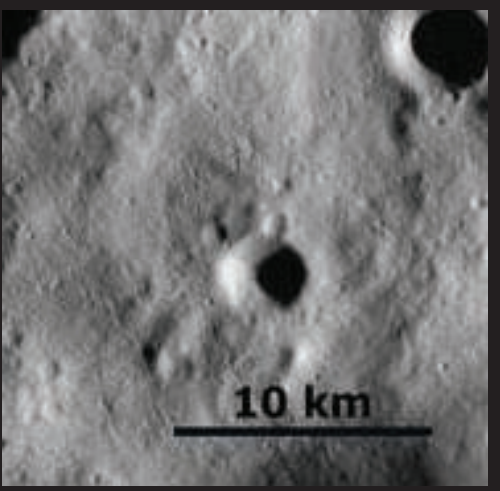
Answer: Time = 4 years, distance = 2.8 billion km, so the speed is A) S = 2.8 billion km / 4 years = **700 million km/year**. B) Converting to an hourly rate, S = 700 million km/yr x (1 year/365 days) x (1 day/24 hours) = **79,900 km/hour**.

Problem 4 - The Space Shuttle traveled at a speed of 28,000 km/hr in its orbit around Earth. How many times faster that the Shuttle does the Dawn spacecraft travel?

Answer: Ratio = (79,900 km/hr) / (28,000 km/hr) = 2.9 . So Dawn is traveling at an average speed that is **2.9 times faster than the Space Shuttle!**

Note: The Space Shuttle is traveling 8 times faster that a bullet (muzzle velocity) from a high-powered M16 rifle! So Dawn is traveling 23 times faster than such a bullet!





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