Impacts & Craters

ASTR 1010

Name:

Overview

In this activity you will calculate crater sizes and environmental factors caused by impacts of meteorites. You will also determine if you could detect a potential impactor and how much time you would have before it hits the Earth.

Objectives

After completing this activity students will be able to:

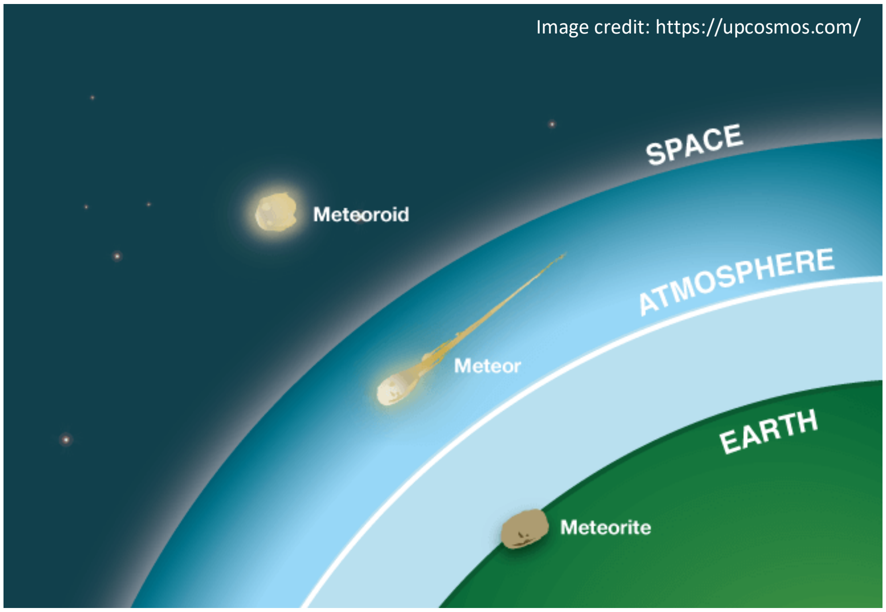
- Calculate the radius of an impactor based on the crater left behind on the surface of Earth and other Solar System bodies.
- Investigate the effects of impacts at various distances from the impact site.
- Calculate the magnitude and distance of a potential impactor to determine if it can be detected from Earth before it arrives.

Note: If a question is labeled "THOUGHT QUESTION**" we are looking for you to show critical thinking/justification in your answer, not a "correct" answer**

Definitions

Here are some terms from lecture that we will be using today in lab:

- **Meteoroid** – a small particle from a comet or asteroid orbiting the Sun.
- **Meteor** – a meteoroid that has entered and burned up in an atmosphere – aka 'Shooting Star'
- **Meteorite** – a meteoroid that has survived its trip through an atmosphere and has landed on the surface of a planet or moon.



- **Period of Heavy Bombardment** – first billion or so years after the formation of the Solar System where leftover fragments of formation impacted upon the surfaces of the major bodies in the Solar System.

- **Albedo** - a measurement of the amount of light reflected from the surface of a celestial object. Ranges from a value of 0 (no light reflected) to 1 (all light reflected).
- **Apparent Magnitude (m)** - how bright an object appears from our vantage point here on Earth. Depends on the object's luminosity AND distance from us.
- **Absolute Magnitude (M)** – how bright a star would appear from a fixed distance of 10 parsecs. Depends only on object's luminosity.
- **Astronomical Unit (AU)** – mean distance between the Sun and the Earth. 1 AU = $1.5x10^{8}$ km

Part 1. Crater Diameter vs. Impactor Size

Several factors are involved in obtaining a reasonable estimate of impactor radius. These include the diameter of the crater (D), density of the impacted surface (ρ_p), the density of the impactor (ρ_m), the gravitational acceleration of the body being impacted (g_p), and the velocity of the impactor (v). Combined, you end up with an equation that looks like this:

$$R = \frac{(0.401)D^{1.28}\rho_p^{0.42}g_p^{0.28}}{\rho_m^{0.42}v^{0.56}}$$ (from de Pater and Lissaur 2001)

Yikes! Let's simply things. Let's assume that **sedimentary rock on Earth is being impacted by a dense rock projectile coming in at a 45-degree angle at 30 kilometers per second** (Note. keep these parameters in mind…you will need them later)**.** This will simplify our equation to:

$$R = 2.26x10^{-3} * \ D^{1.28} \qquad (Equation\ 1)$$

In our simplified equation, **D (diameter of the crater)** and **R (radius of impactor)** will be in units of meters**.** With our equation simplified and our reminder about converting units, it's time to calculate impactor sizes!

1. Barringer Crater in Arizona (www.barringercrater.com) is a well-preserved impact from around 55,000 years ago. It has **a diameter of 1200 m.** Use Equation 1 to calculate the radius of the impactor.

R = [ ] m

NOTE. Be careful with your parentheses! If you are using Excel or other spreadsheet program, type Equation 4 in like this: =2.26E-3*(D^1.28)

Many movies are filmed in the Atlanta area. Let's pretend we are science advisors for an upcoming science-fiction disaster film. Premise of the film – Metro Atlanta is completely destroyed by a large impactor motivating a misfit team of not scientists to get revenge on some space rocks! Assuming everything inside the perimeter is destroyed, the **diameter of the crater will be 40,000 m**. Calculate how large of an impactor would need to be CGI-ed in order to appropriately motivate the heroes to avenge Atlanta!

Once you calculate the radius of the impactor in meters using Equation 1, divide by 1000 to convert to kilometers and record your answer. Then divide your answer in km by 1.6 to convert to miles.

2. a. R = ☐ m

   b. Covert R to km → = ☐ km

   c. Covert R to mi → = ☐ mi

Going back in time 66 million years, the Cretaceous–Paleogene (K–Pg) extinction event, which resulted in the mass extinction of around 75% of plant and animal life on Earth, was likely caused by the Chicxulub impactor. Located on the Yucatán Peninsula, the Chicxulub crater **has a diameter of 180,000 m**. Using Equation 1, how big was the impactor?

Image credit: www.smbc-comics.com

3. a. R = ☐ m

   b. Covert R to km → = ☐ km

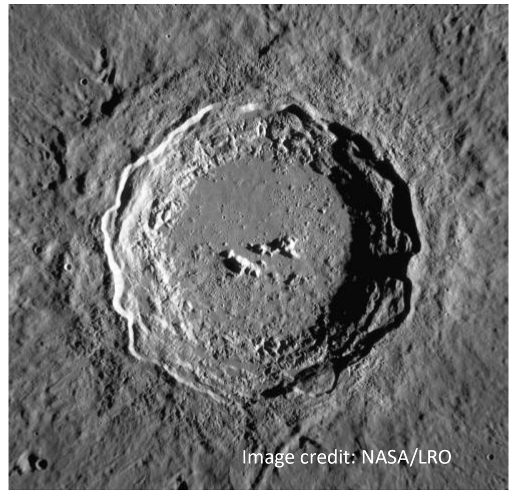
   c. Covert R to mi → = ☐ mi

Earth is not the only body in the Solar System to be influenced by impacts. Let's visit the Moon and Mercury. Because of different densities and gravitational acceleration on each body, when calculating the impactor size on the Moon you will use Equation 2 and for Mercury you will use Equation 3. Crater diameter values (D) still need to be in meters!

$$R = 1.49x10^{-3} * D^{1.28} \qquad (Equation\ 2 - for\ the\ Moon)$$

$$R = 1.73x10^{-3} * D^{1.28} \qquad (Equation\ 3 - for\ Mercury)$$

One of the most prominent craters on the Moon is Copernicus. With a crater **diameter of 95,000 m**, how large of an impactor was required to create Copernicus? The Moon has about 1/6 of the Earth's gravitational acceleration, so remember to use Equation 2!



4. a. R = ☐ m

   b. Covert R to km → = ☐ km

   c. Covert R to mi → = ☐ mi

Now compare how impactor size changes based on gravitational acceleration and composition. Using the crater size of left by the Chicxulub crater **(diameter = 180,000 m)** and Equation 2, how large of an impactor would have to had to hit the Moon to make the same sized crater?

5. a. R = ☐ m

   b. Covert R to km → = ☐ km

   c. Covert R to mi → = ☐ mi

6. Comparing the impactor sizes from Questions 3 and 5, do you need a larger impactor on Earth or the Moon to make the same sized crater?

☐

Moving to Mercury, let's have a look at the Caloris Basin, one of the largest impact basins seen in the Solar System. The Caloris Basin has **a diameter of 1,400,000 m.**

Using Equation 3 (because Mercury has 38% of the Earth's gravitational acceleration), how large of an impactor was needed to create this feature?

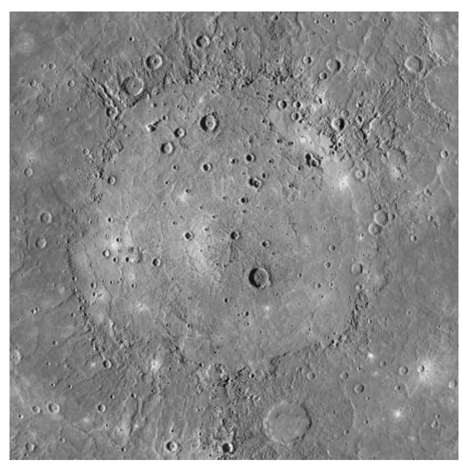


Image credit: NASA/MESSENGER

7. a. R = ☐ m

   b. Covert R to km → = ☐ km

   c. Covert R to mi → = ☐ mi

Part 2. Effects of an Impact!

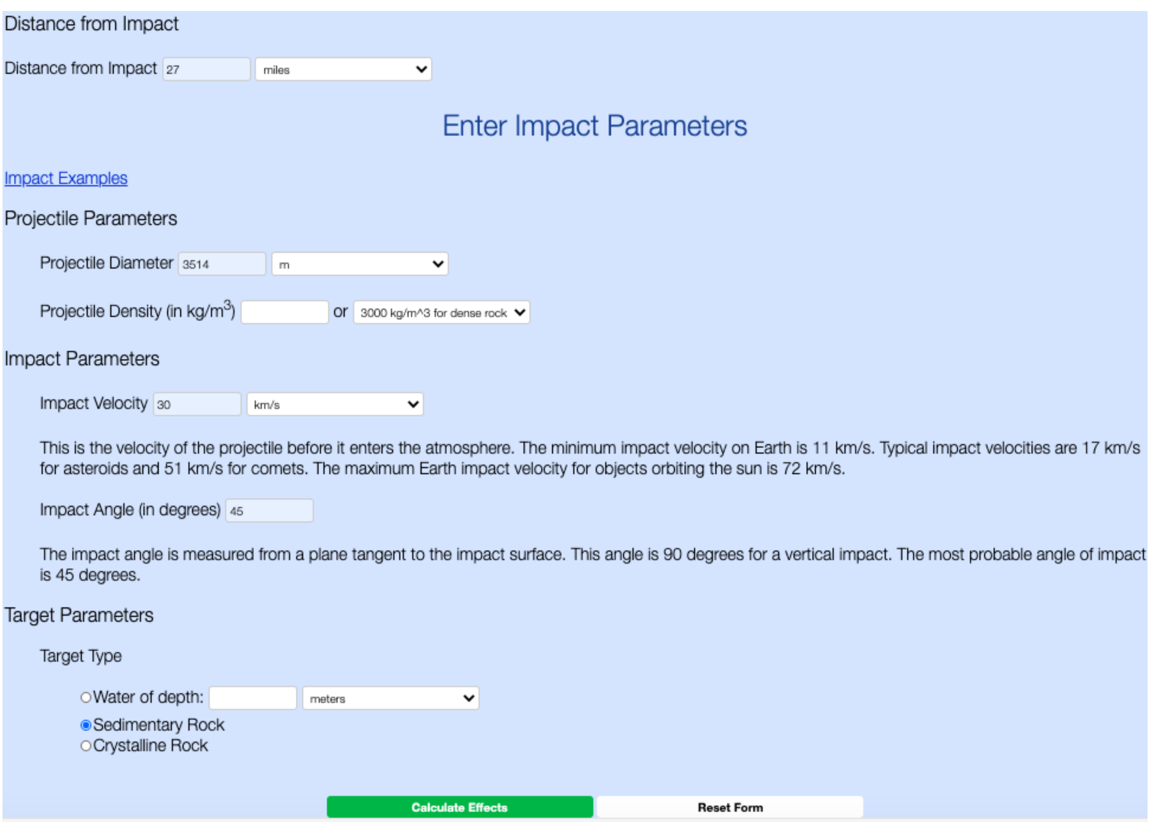
Now that you have calculated impactor sizes, you are ready to investigate the impact (!) these impactors on the environment. Depending on the size of the impactor damage could vary between a hole in a roof to global cloud cover similar to "nuclear winter". For Part 2 of this activity, we will focus on the immediate environmental effects using an impact simulator created by Imperial College London and Perdue University. You can find the simulator here:

https://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/

This website runs a computer simulation detailing results from an impact at a particular distance away from an impact site on Earth's surface. We will use the Atlanta-destroying, sci-fi movie projectile from Question 2 and let's start close to Atlanta in Peachtree City, GA. To avoid confusion, here are the parameter values you should enter into the simulator:

- **Distance from impact:** 27 miles (change units to miles)
- **Projectile Diameter:** 3514 m (Note. You can divide this value by 2 to double check your answer for Question 2)
- **Projectile Density:** Choose '3000 kg/m^3 for dense rock' from drop down menu
- **Impact Velocity:** 30 km/s
- **Impact Angle (in degrees):** 45
- **Target Type:** Select 'Sedimentary Rock'

Your page should look like this:



Your TA will walkthrough of how to set up the simulator in the pre-lab discussion. If you have a match, click 'Calculate Effects'.

The resulting page will list the following information: Your inputs, energy, major global changes, crater dimensions (which will be different than our calculation due to the more accurate nature of the simulator), thermal radiation, seismic effects, ejecta (debris excavated during the impact is deposited on the Earth's surface around the impact crater), and air blast. **Note. If you get an error in your output, double check the units of your input values or ask your TA for help!**

8. List (in your opinion) the worst effects from Thermal Radiation. What do you think will happen to most humans? How soon does this happen after impact?

9. What is the Richter Scale magnitude of the earthquake from this impact? What is the worst effect listed by the Mercalli Scale Intensity? How soon does this occur after impact?

10. How deep is the ejecta (listed as thickness) at your location? What is your position relative to the ejecta deposit?

11. What is the sound intensity of the air blast and when will it arrive? List one consequence of this air blast.

12. **THOUGHT QUESTION.** Looking over questions 8-11, how ruined would the day of a person 27 miles from this impact be?

To make the day slightly better, **<u>PRESS THE BACK BUTTON ON YOUR BROWSER</u>**. Let's **move 61 miles away** to Athens (change 'Distance from Impact' to 61 miles **<u>BUT LEAVE ALL OTHER PARAMETERS THE SAME</u>**). Click 'Calculate Effects'.

13. Many of the effects will be the same in Athens, but a few things are different. How thick is the ejecta? Describe how the seismic effects are different than in Question 9.

Continuing our quest for improving our day, click the back button on your browser. Making our location Savannah, **which is 226 miles away.** After changing the distance from impact and calculating effects, you will notice in general some effects are getting less severe. Each effect arrives at different times, with the air blast arriving last.

14. How long after impact does the air blast arrive in Savannah? What percentage of trees are knocked down or stripped of branches and leaves? What is the average ejecta thickness?

Finally, let's get out of state and head to Miami! Click the back button on your browser, set the **distance from impact to 605 miles**, and calculate effects.

15. What thermal radiation would you experience in Miami? What is the most dramatic seismic event you would experience? What is the thickness of the ejecta? What effects does the air blast have in Miami?

Part 3. Impact Prevention

For the final part of this activity and to complete our movie science quest, we will do some simple calculations to determine if we could see an object coming. The absolute brightness of an asteroid is determined by its diameter and its albedo (how well it reflects light). The darkest asteroids have an albedo of 0.05 and the absolute magnitude (M) can be estimated by the following equation:

$$M = -5 * \log(2R) + 34 \qquad (Equation\ 4)$$

Where R is the radius of the impactor in meters. Using the R value for the Atlanta-destroyer in Question 2, calculate the absolute magnitude of the impactor.

NOTE. Be careful with your parentheses! If you are using Excel or other spreadsheet program, type Equation 4 in like this: =(-5*log10(2R))+34

16. M =

Luckily for Earth-based creatures, NASA has a Center for Near Earth Object Studies that is constantly computing asteroid and comet orbits and their odds of Earth impact. The typical ground-based telescope looking for these objects is about 1 meter in aperture. These telescopes can detect objects down to an apparent magnitude (m) of about 20.
Note. Remember with magnitudes, the smaller the number, the brighter the object!! The full Moon has an apparent magnitude of around -12.6.

Using the following equation, calculate the distance in astronomical units (AU) at which the asteroid can be detected by a 1-meter telescope. **Let m=20 and use the M value calculated in Question 16.**

$$d = 10^{(m-M)/10} \qquad (Equation\ 5)$$

Note. BE VERY CAREFUL WITH YOUR PARENTHESES! If you are using Excel or other spreadsheet program, make sure you type in Equation 5 like this: =10^((m-M)/10)!!

17. d = AU

Finally, in years, how long will it take for this object to hit Earth if it were on a crash course from this distance? Assume that the impactor is traveling 30 km/s and remember that 1 AU = 150,000,000 km.

18. time = months

19. Do you think we would be able to see such an impactor before it reached the Earth?