Planetary Magnetism

How crucial is a planet's magnetic field?

Explore & Explain:

1. Pour the iron filings onto the top sheet. Pour them so that they are evenly spread out across the whole sheet. Use about a teaspoon's worth (as much as would fit in a typical spoon [flattened not heaping]).

   What do you see when you pour the iron filings over the entire sheet?

   What do you think is hiding beneath (don't peek!)?

2. Add the two extra DVD cases (or whatever "spacer" your teacher has provided you) to each side of the set up (see pictures below) and then place the clear acrylic sheet on top.
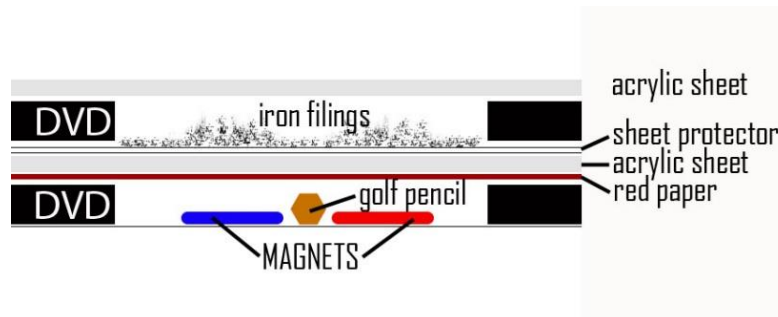

Figure 1. Diagram showing the model after step 2.

Figure 2. Photo showing the model from the side.

Warning: keep all electronics, credit cards and other magnetized materials (including cell phones and computers) AWAY from magnets at all times! Also, magnets that are incredibly strong can cause pinching injuries (or worse if swallowed) and must be handled with caution.

3. Now place your magnet on top of the acrylic sheet over the area without underlying magnets first… move it around in small circles without going over the underlying magnets.

What happened to the iron filings when you placed the magnet on top and slowly moved it around?

4. Try moving the magnet in the same small circles, but this time over the underlying magnets.

What happened to the iron filings when you moved the magnet over the underlying magnets?

Elaborate:

Okay, let's start over and use some different terms this time:

Iron filings = <u>charged particles</u> in Mars's upper atmosphere (the ionosphere)
Cow magnet = the Sun's magnetic field carried by the solar wind
Hidden magnets underneath = underlying magnetic areas in the surface (crust) of mars
Lower acrylic sheet = lower, more dense atmosphere of Mars

The model that you've been using is a very simplified analogy for Mars's atmosphere. It isn't a perfect representation, but it's useful to learn from. Here's what each part of the model represents:
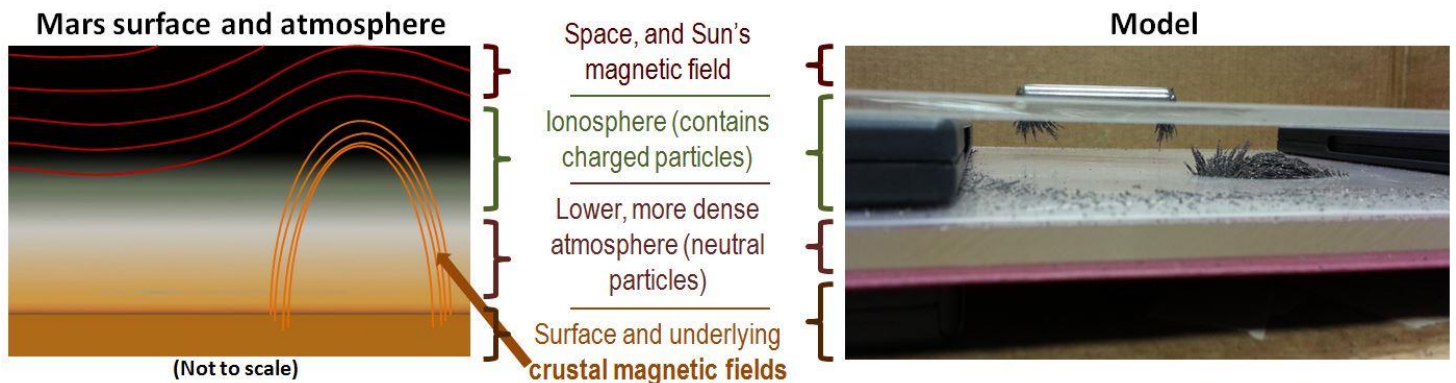

Figure 3. Comparison between the Model and Mars surface and atmosphere.

From here on we'll use the names of what the objects represent…

5. Remove the *charged particles* (iron filings) and redistribute them evenly over the entire surface, just like you did in step #1. And again, add the two extra DVD cases to each side of the set up and then place the clear acrylic sheet back on top. Stop here for a second.

   For the charged particles that *aren't* near the underlying magnets, what is the main force pulling them down? (hint: it's the same force pulling you to the ground)

6. Place the *Sun's magnetic field* (cow magnet) on top, and move it around in small circles. Experiment with moving the Sun's magnetic field around the entire area.

   What is the main force pulling up on the charged particles?

   (Technically, magnetism is one aspect of a fundamental force called *Electromagnetism*)

On Mars, the Sun's magnetic field is constantly moving over and past the planet. It sweeps over the atmosphere and then continues on into space.

7. Try modeling this: drag your Sun's magnetic field over the model and keep dragging it until it leaves the vicinity of Mars's atmosphere altogether (i.e. off and away from the top acrylic sheet).

   What happened to the charged particles that were caught by the Sun's magnetic field? Were they left behind in Mars's atmosphere? Or were they dragged off into space?

Were any of the charged particles left behind in Mars's atmosphere? If so, where were they?

Figure 4. Iron filings attracted to cow magnet.

Did the underlying surface magnetic field affect the Sun's magnetic field's ability to strip away the charged particles?
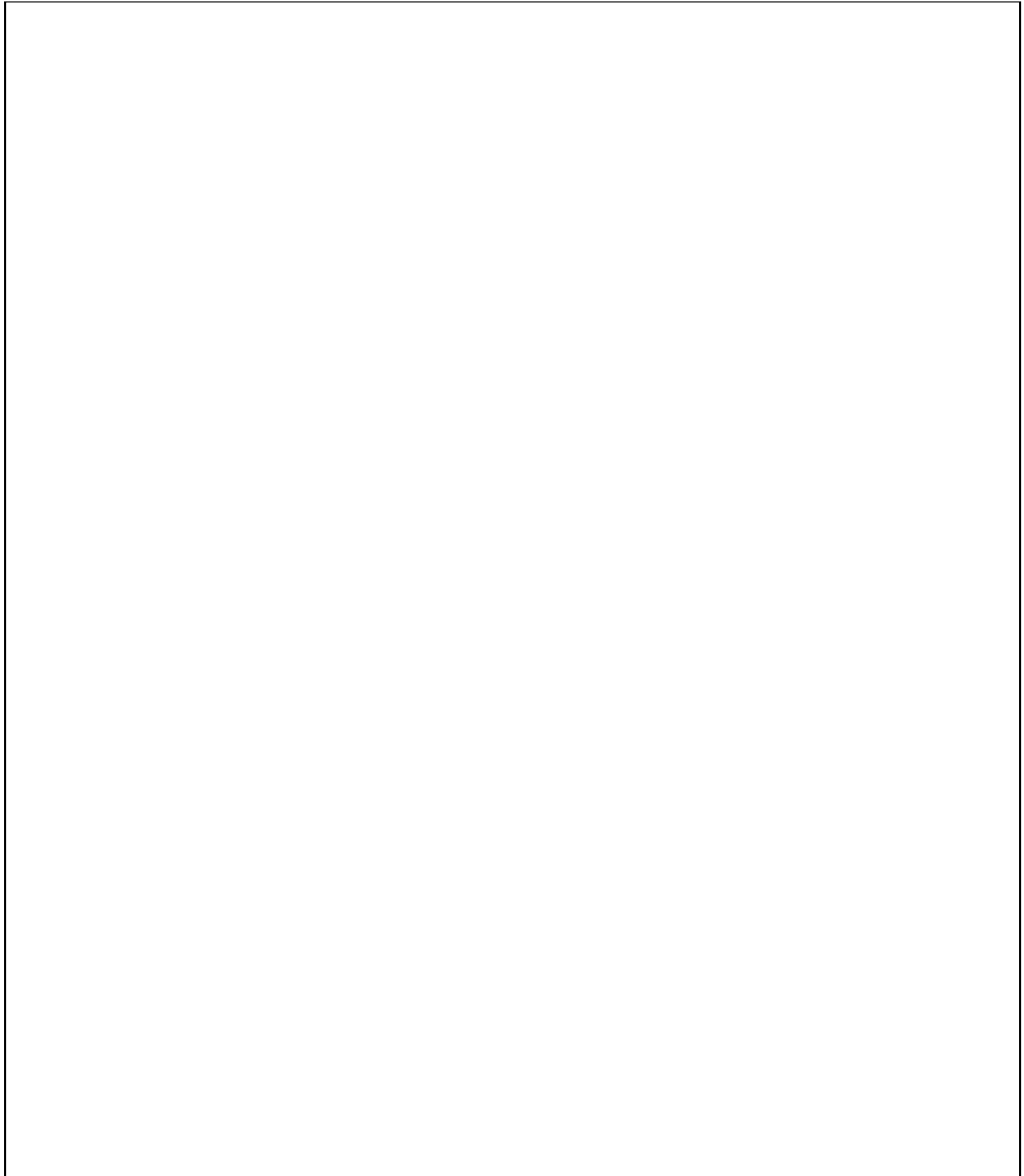
Based on your observations, does a planet's magnetic field help to protect its atmosphere from being stripped away by the Sun? Yes or no?

What about gravity?

If the force of gravity were a LOT stronger, do you think it would help a planet keep more of its atmosphere? Why or why not?

Final Reflection:

It's time to put everything together! Draw a diagram or describe the relationship between Mars' magnetic field, atmosphere, and the solar wind and what you've modelled in the activity.

*** Stop here and wait for your teacher to tell you to continue ***

Going Further: What's up with Venus?

Like Mars, Venus has no strong global magnetic field. In fact, it doesn't even have smaller crustal magnetic fields. But, unlike Mars, Venus does have a very thick atmosphere. This is very puzzling based on what we've just learned, isn't it? Well, there are several hypotheses about how Venus is able to have a very thick atmosphere, even with no strong magnetic field to shield it from the solar wind.

Here are some clues:
- The gravitational force near the surface of Venus is 2.38 times stronger than the gravitational force near the surface of Mars.
- Volcanoes emit a lot of gases. Venus has more volcanoes than any other planet in the solar system, although it is unknown how many of those volcanoes (if any) are still active.
- The solar wind strips away the atmosphere of a planet *very* slowly.
- Venus is about 4,500 million years old. We can only tell that it hasn't had a strong magnetic field for the most recent 500 million years; before that it is unclear.

Based on the above clues, write a paragraph explaining some possible reasons that Venus has a thick atmosphere even with no strong magnetic field:

Going Even Further: What's the math?

Grades 8-12

Algebra pre-requisite

Let's look closer at one of the individual charged particles over a part of Mars with no underlying crustal magnetic field. There are a lot of different types of charged particles in the upper atmosphere, but for this example we'll look at an Oxygen ion (singly ionized).

In a *very* simplified case, the two main forces acting on the charged particle are magnetism (pulling up) and gravity (pulling down):
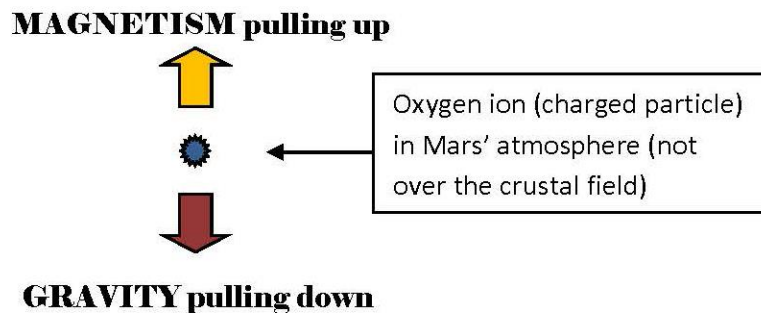
The basic equation for **gravity** is:

$$F = \frac{GM_1 M_2}{r^2}$$

F = Force in Newtons [(kg•m)/s^2]

G = Gravitational Constant = **6.67 x 10^{-11} m^3/(kg•s^2)**

M_1 = Mass of Mars = **6.4 x 10^{23} kg**

M_2 = Mass of an Oxygen Ion = **2.66 x 10^{-26} kg**

r = Distance between atom (at 200 km above surface) and center of Mars = **3.6 x 10^6 m**

In this scenario, the relevant equation for the force due to **magnetism** is:

$$F = qvB$$

F = Force in Newtons [(kg•m)/s^2]

q = Charge = **1.6 x 10^{-19} Coulombs (C)**

v = Typical velocity of Sun's magnetic field (km/s) = **4 x 10^5 m/s**

B = Typical strength of Sun's magnetic field in Teslas [kg/(C•s)] = **3 x 10^{-9} Teslas (T)**

Calculate which force is stronger on Mars, gravity or magnetism (show your work):

Which force is stronger on Venus, gravity or magnetism? Remember to show your work (hint: the gravitational force near the surface of Venus is 2.38 times stronger than the gravitational force near the surface of Mars.)

Final question: If the most important variable is the velocity of the solar wind, what is the minimum velocity needed to overcome the force of gravity on Mars? On Venus?

Mars	Venus