

Bite-size Information

- ◆ Don't forget to renew your subscription!
- ◆ Labels for the "Slice of the Earth"
- ◆ Free and low-cost materials from USGS

Main features

- 2 Earth systems and their interactions
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Big Picture Science

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Earth Systems Concepts

Give your students a framework for how the planet functions

An understanding of the spheres of Earth (lithosphere, hydrosphere, atmosphere, and biosphere) and their interactions is an important framework for studies in Earth and life sciences.

It is so easy to take the Earth for granted (no, not "granite", "granted"). It is always there and seems to change very little. We get a different view if we think of **Earth as a complex system**, with energy always flowing in and out and matter remaining nearly constant, but cycling through various forms. If we realize that there are several spheres that interconnect on the surface of this planet, and that the surface is dynamic, shaped by the action of several interacting cycles, then we come closer to a realistic view of this place.

The view that Earth is a system of spheres is an important organizing concept for both Earth and life science studies. Under the name of Earth systems science, this concept framework is being used at many levels of education. The most commonly studied spheres are: the sphere of the solids that make up the Earth's crust and the top of the mantle (**lithosphere**); the gases above its surface (**atmosphere**); the water that cycles there (**hydrosphere**); and the life that makes up a unique, but thin layer (**biosphere**). Other sphere concepts are the geosphere (Earth's solids all the way through, not just on the surface; some call this the lithosphere), the cryosphere (water in its solid state), and most importantly, the anthrosphere (humans and their activities, and how they influence the other spheres).

Students need to know more than just the names of the spheres. The important part is **how these spheres interconnect** and affect each other. To understand these interactions, students need to know the basic working parts of each sphere, and they need to study several important underlying physical science concepts. These include states of matter, density, heat transfer by convection, the electromagnetic spectrum, and absorption and radiation of energy.

As you study the changes in the spheres, think about the energy that drives that change. All changes involve energy. For instance, heat transfer and gravity's pull are behind the cycling of air in the troposphere. The Sun's energy drives the winds, which in turn drive the ocean currents.

From the Earth systems concepts, you can go on to study the geologic cycle, which drives the changes in the Earth's lithosphere. This is actually the summation of three different cycles, the rock cycle, the hydrologic or water cycle, and the tectonic cycle of the plates that make up the crust. I will address the geologic cycle in a future newsletter. ♦

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Consider the Earth

Last fall I bought the text used in introductory courses at Colorado School of Mines. It was not a geology text, but instead the *Geosystems* book listed in the references. It seems that Earth systems science is a good foundation for college studies; it can also follow the first Great Lesson, and lead into more Earth study.

Sometimes when you start an Earth-related topic, it helps to see the actual proportions of the Earth's layers. On page 5, there are directions on how to make a scale model of a "slice" of the Earth. You can use the labels I have given to introduce the layers, but students may be interested in writing their own labels.

Please remember to renew your subscription. Thank you.

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Description of Earth system components and their interactions

The lithosphere is composed of the Earth's **crust and its uppermost mantle**. This layer is cooler and therefore more rigid and brittle than the semi-liquid layer just beneath, the asthenosphere ("weak sphere"). The lithosphere floats on the hot, pliable asthenosphere. When glaciers form, they press down on the lithosphere and cause it to sink. As the glaciers melt, the lithosphere springs back and rises in elevation (this process is called isostatic rebound). The whole lithosphere is 70-100 kilometers thick. Its lower border is not a chemical boundary, but rather a physical one, since the rest of the mantle is less solid. The crust portion is thinner under the oceans and thicker under the continents.

The lithosphere is **broken into several pieces called plates**. These plates slowly move, driven by the upwelling of heat from deeper in the mantle. At spreading centers in the ocean, the plates move apart, which allows new magma to well up and add to the plate margin. The extra material at the other side of the plate usually dives back down into the mantle, where it is re-melted (the process of subduction). The plate can also simply grow, with the surrounding plates subducting under it. The lithosphere is the zone of earthquakes. They occur from near its surface to deeper inside the Earth where the diving plates are melting and breaking up.

The lithosphere holds uncombined chemical elements and minerals (pure substances), as well as rocks and soil (mixtures). It has at least a trace of all the naturally occurring chemical elements. It is richer in relatively light elements, with the heavier ones concentrated in the deeper layers of the Earth. The most common elements of the crust are oxygen (45.2 %), silicon (27.2 %), aluminum (8 %), iron (5.8 %), calcium (5.1%), magnesium (2.8%), sodium (2.3%), potassium (1.7%), and titanium (0.9%). These make up 99% of the crust. (Figures from *Earth: An Introduction to Geological Change*, 1995, by Sheldon Judson and Steven Richardson.) The first two of these elements, oxygen and silicon, usually combine, forming silicates, which are present in almost all common minerals. There is much more happening with the elements in the crust than is evident from these figures. Many elements of living things cycle between the lithosphere, hydrosphere, atmosphere, and biosphere. Examples include carbon, sulfur, and nitrogen.

There is a difference between the rocks that make up the oceanic crust and the continental crust. The oceanic crust solidifies from basaltic magmas, which have a high content of magnesium and iron and a relatively low silica content (about 50%). The rocks are called "mafic", which is derived from "magnesium" and "ferric", a Latin term for iron. Mafic rocks are darker in color and denser than the felsic rocks that make up continental crust. The name "felsic" comes from "feldspar" and "silica", two minerals that are more abundant in these rocks. The result is that oceanic crust is denser than continental crust. When an ocean plate meets a continent, it moves beneath the thicker, land plate. The felsic and mafic magmas have different properties, which are reflected in the volcanoes that they form. Basaltic (mafic) magmas are more fluid and form shield volcanos. Felsic magmas are more viscous and trap more gas. The volcanoes they form have more explosive eruptions. They take the strato-volcano shape, a steep cone.

Interactions: The lithosphere contributes water vapor, carbon dioxide, sulfur dioxide, hydrogen, and dust to the atmosphere, via volcanic eruptions. The lithosphere not only provides a home for land-dwelling and benthic organisms of the biosphere, it provides vital mineral nutrients. Its form effects the flow of water in the hydrosphere. People use many resources from the lithosphere, including building stone, petroleum, metal ores, and precious gems.

The hydrosphere. Water is such a special molecule that it merits its own sphere. The hydrosphere is all of the **surface water** on Earth, plus the **water in the atmosphere** and that in the crust near its surface (**groundwater**). The water exists naturally in all three states of matter, solid, liquid, and gas (vapor). It is the only common substance that does so. Earth is the only planet known to have liquid water, as a result, the only planet with life. Water covers over 70% of our planet's surface, and gives it the names "Blue Planet" and "Water Planet".

The special properties of water include its high heat capacity. This means that it takes a lot of energy to change the temperature of water. (In contrast, a small amount of heat will raise the temperature of a metal.) This enables water to act as a buffer and stabilize the temperature of the surrounding land. It also means that the bodies of large animals hold heat well. It takes an extra amount of heat to change the state of water. If ice warms to 0° C, it must absorb extra heat just to break the crystal structure of the solid and change it to a liquid before the temperature can rise. This heat is called the latent heat of fusion. Similarly, it takes extra heat (the latent heat of vaporization) before water at 100° C will change to water vapor. These two latent heats result in the slower evaporation of water (helped by its high surface tension) and slower freezing and melting. When water evaporates, the surrounding area cools as it donates the heat required. The solid state of water is less dense than the liquid, so ice floats. If it didn't, ice would accumulate at the poles and reduce the liquid water supply. Ponds would always freeze solid. The greatest density of water occurs at about 4° C (38° F), so there is a layer of liquid water at the bottom of frozen lakes and ponds in which fish and other aquatic life can shelter.

Earth system components and their interactions (continued)

The water of the hydrosphere is not all the same. Over 97% of it is salt water in the oceans. The rest is fresh water. A little over 2% of all water is frozen, as glaciers and polar ice caps. Groundwater holds 0.6% of the water, with lakes, ponds, rivers, and wet lands holding less than 0.1%. A very small percentage of the Earth's water is water vapor in the atmosphere.

In the oceans, water acts as a medium for energy transport. The great ocean currents move heat from the tropics to the middle latitudes. Without the Gulf Stream, northern Europe would be much colder.

The water cycle moves water through the hydrosphere. There is a large difference in the average time water spends in each location. Water in the atmosphere resides there for about 10 days. This is the average time from when the water is evaporated to when it leaves as rain or snow. In rivers and streams, the water changes in weeks. It may take years to completely replace the water in lakes and swamps, but aquifers have held the record for the longest time that fresh water stays in one place. Their water can stay from years to millennia. An aquifer is a subterranean deposit of water within porous rock or gravel. People can drill wells into an aquifer and pump the water out, and they are able to remove it much faster than natural processes can put it in. If they let pollutants get into an aquifer, it may take a very long time before the water is clean again.

Groundwater exists in two forms, the first as moisture in the subsoil and rocks where there are still air spaces between the soil particles and water. This is the zone of aeration. If you dig deeper, you encounter the zone of saturation, where water completely fills the pores. The top of this zone is called the water table. Where the water table intersects the surface, springs and streams form.

Interactions: The hydrosphere greatly affects the landforms of the lithosphere, since water transports sediments and dissolves substances from rocks and soils. The amount of water, along with the temperature range, determines the type of biome that can exist in an area. Water vapor in the atmosphere affects heat transfer through the air; dry air insulates and moist air conducts heat better. Clouds (water droplets) screen the Earth's surface from the Sun's heat, but they also hold in heat radiating from the Earth at night. Many organisms use water evaporation to cool themselves.

The atmosphere is a mixture of gases that begins at the Earth's surface. The atmosphere has changed dramatically since the early days of the Earth. Soon after the planet formed, the primordial atmosphere contained water, hydrogen cyanide, ammonia, sulfur, and methane. By four billion years ago, the atmosphere probably was mainly water, carbon dioxide, and nitrogen, with little or no oxygen. By three billion years ago, living organisms had increased the oxygen to at least 1%. From there, the process of photosynthesis continued to raise the atmospheric oxygen and lower carbon dioxide until it reached the present levels of 21% oxygen and 0.036 carbon dioxide about 0.6 billion years ago. Now the atmosphere is in dynamic equilibrium. This means that gases are continually being added and subtracted, but the composition stays about the same. Phototrophic organisms continually add oxygen to the atmosphere and remove carbon dioxide. We don't know how the carbon dioxide that people put into the atmosphere affects this equilibrium.

We divide the atmosphere into several **layers based on temperature**. The lowest layer is called the **troposphere** ("changing or turning sphere"). This layer gradually cools from bottom to top, and temperature defines the upper limit, which occurs at -57°C (-70°F). Its thickness varies with latitude and season. At the equator, the troposphere is about 18 km (8 miles) thick. It tapers to 8 km (5 miles) over the poles. The troposphere gets its name because the air within it is always mixing. The air at the surface heats and rises. As it moves toward the top of the troposphere, the air cools and contracts so that it is more dense, and descends. Winds stir this layer. This is where weather happens and most clouds form, including smog clouds. The troposphere has more than 75% of the total mass of the atmosphere.

At the top of the troposphere lies the tropopause ("turning stop"), the boundary where the temperature stops falling as the altitude increases. Above it lies the **stratosphere** ("layered sphere"), which extends to about 50 km (31 miles) above the surface. Here is where the ozone layer forms. Ozone is three oxygen atoms joined together. It absorbs ultraviolet radiation that would otherwise destroy life on the Earth's surface. The absorption of radiant energy causes the temperature to rise from -57°C (-70°F) to 0°C (32°F) in this layer. Jet streams, bands of concentrated, high-speed wind, occur near the tropopause and greatly influence weather patterns. Passenger jets fly in the stratosphere.

Next up is the **mesosphere**, ("middle sphere") where the temperature again falls. The coldest layer of the atmosphere is here, with a temperature of -90°C (-130°F). The density of molecules is very low. The mesopause marks the upper boundary of the mesosphere, at about 85 km (53 miles) above Earth's surface.

The **ionosphere**, a layer defined by its ability to absorb high-energy electromagnetic radiation, starts in the mesosphere and continues upward. Here atoms absorb energy from X-rays and gamma rays, which knocks electrons

Earth system components and interactions - continued

away from them. Since they no longer have the same number of protons and electrons, the atoms become charged particles that are called ions. The ionosphere has several layers that reflect radio transmissions, especially in the AM band. These layers change from day to night, which is why you can receive AM broadcasts from distant places at night, but not during the day.

Continuing up the atmospheric layers based on temperature, we next reach the **thermosphere**. This layer sounds as if it were hot, and indeed it is, with temperatures of 1200° C (2200° F) and more. If you could hold your hand there, however, it would not feel warm. The atoms and molecules there are so far apart, few would strike your hand and transfer the heat. (Heat is the energy of moving atoms and molecules. Temperature is a measure of how much energy the atoms and molecules have. It is independent of how many there are.)

The auroras form in the thermosphere. They are clouds of glowing ions, caused by solar wind, clouds of electrons and ions released from the Sun. Solar ion storms can put so much energy into the thermosphere that radio communications can be disrupted. The bright streaks of meteors start in the thermosphere and normally do not extend past the mesosphere.

The thermosphere ends at the thermopause, about 480 km (300 miles) above the surface. From there, the atmospheric layer is called the **exosphere** ("outside sphere"). It is hard to consider this part of the atmosphere, since it is practically a vacuum, with only a few hydrogen and helium atoms, which are too light for Earth's gravity to hold.

Interactions: The atmosphere filters solar energy before it reaches the lithosphere. It transports sediments in dry areas (as dust or sand storms). Its winds redistribute solar energy from the tropics to the middle latitudes, and drive the great ocean currents. It transports water from the oceans to the land. It provides vital screening from high energy solar radiation and thereby protects life. It holds oxygen and carbon dioxide, gases produced and required by the biosphere.

The biosphere is that miraculous, thin layer in which life occurs. It starts at the bottom of the ocean floor, where thriving communities of organisms feed on sulfur from deep-sea volcanic vents and reaches upward to the highest mountain peaks. It includes the lower part of the atmosphere, since organisms can survive there. In most of the biosphere, there is a **tightly interwoven community** of a myriad of organisms, ranging from microscopic size to easily visible. Classified on their mode of nutrition, they can be grouped as producers, consumers, or decomposers. These communities co-evolve over thousands to millions of years. The biosphere is **limited by physical** (temperature, light) **and chemical factors** (oxygen, water, acidity, mineral nutrients). The range of livable conditions is wider than you would think, however. There are microbes that can live at temperatures ranging from below freezing to above the boiling point of water. Others live in strongly acid conditions, in the absence of oxygen, or at high salt concentrations. For higher organisms, the livable temperature range is from just above freezing to about 48° C (118°F). The harsher the conditions, the fewer the species that can live there.

Interactions: The living world is tightly linked with the lithosphere in soils. The growth of plants greatly influences the stability of surface layers of soil and rock. Plants transfer large amounts of water from the soil to the atmosphere with the process of transpiration. Phototrophic organisms add oxygen and remove carbon dioxide from the atmosphere. In the ocean, growth of plankton organisms adds cloud condensation nuclei to the atmosphere, which cause more clouds to form. ❖

Labels for the "Slice of the Earth" Model on page 5 (If students have not studied density, omit those figures.)

Inner core – iron, solidified by the high pressure,
density = 13.5 g/cm³

Outer core – liquid iron, generates Earth's magnetic field,
density = 10.7 g/cm³

Gutenberg discontinuity

Lower mantle – a mixture of iron, magnesium, silicates;
the minerals olivine and high-density perovskite

Upper mantle – a mixture of olivine, silicates, and
peridotite

Average mantle density = 4.5 g/cm³

Lithosphere – uppermost mantle + crust

Asthenosphere – "weak sphere", like hot plastic, with
molten pockets, density = 3.3 g/cm³

Uppermost mantle – rigid, cooler than the asthenosphere
Mohorovicic discontinuity (Moho)

Oceanic crust – dark-colored, more dense, low silica,
mafic minerals, density = 3.0 g/cm³

Continental crust – lighter colored, less dense, higher
silica, felsic minerals, density = 2.7 g/cm³

Other labels: spreading center, subduction zone,
troposphere, stratosphere, mesosphere, thermosphere

A Slice of the Earth – a scale model

What it is: A model of the layers of the Earth. The scale is 1:1,000,000 (1 meter = 1000 km , 1 mm = 1000 meters)

How it looks: A paper wedge that is about 7 meters long, starting at a width of 76 cm (30 in) at the “surface” and tapering to a point at the “center of the Earth”.

What you need to make it:

A roll of white or light colored banner paper that is at least 7 meters (23 feet) long and about 76 cm (30 inches) wide.

Materials to paint or color the sections. A metric measuring tape or meter stick. Metric ruler

Colored pencils or markers. About 6.5 meters of heavy, non-stretchy string

What you do:

1. Tie a large knot near one end of the string. Carefully measure out 6.37 meters and tie a knot at that mark.
2. Unroll the banner paper and cut off a piece that is about 7 meters long.
3. Mark an “x” half way across of the banner paper, a few cm from the end. Have one person hold one knot of the string on the “x”. Another person takes the string to the other end of the paper and holds (or tapes) a pencil at the other knot. Then the second person draws a line across the paper, being careful to hold the pencil perpendicular to the surface and keep the string taut. This line represents the surface of the Earth. There is very little curvature.
4. If you wish to trim the paper into a wedge (as though it had been sliced out of sphere), do steps 5 and 6. If you wish, you can skip steps 5 and 6 and draw the model on the banner paper as is, without trimming it into a wedge.
5. With the first person still holding the knot on the “x”, the second person holds the other knot at the outside edge of the paper. A third person uses a pencil to draw a line along the string from the “x” to the edge of the paper.
6. Cut along the line. This trims away one side of the wedge. Fold the paper in half and trace the same line on the other half of the paper. Cut away that part as well. You should have a long, tapering wedge.
7. Measure the following marks from the “x”. Draw a short line at each mark. (If you didn’t trim your banner paper into a wedge, you will need to tie a knot in the string at the measurements and use it like a compass to draw an arc.)
 - . Inner core ends at 1.22 meters.
 - . Outer core starts at 1.22 meters and goes to 3.47 meters. (2.25 meters from last mark)
 - . Lower mantle starts at 3.47 meters and goes to 5.7 meters. (2.23 meters from last mark)
 - . Surface should be about 0.67 meters (67 cm) from the last mark, making 6.37 meters total.
 - . Measure from the surface down for the rest of the layers. The thickness of the asthenosphere, uppermost mantle, and crust will vary depending if the crust is under the ocean or under land.
 - . Upper mantle starts at 67 cm from the surface and goes to 25 cm from the surface.
 - . The asthenosphere starts at the top of the upper mantle (25 cm from the surface). It goes to the base of the uppermost mantle, the layer just under the crust.
 - . The lithosphere (crust + uppermost mantle) varies from 7 to 10 cm in thickness on this model, with the thickest part under mountains. You can draw a variety of structures for the lithosphere. You may wish to ignore the scale on the horizontal dimension, since you can show more structures. See the book references on page 6 for helpful illustrations of the lithosphere, including subduction zones.
 - . Average ocean depth is about 4000 meters, so mark off 4 mm from the surface for oceans. If you wish to add a spreading center between two ocean plates, the ocean should only be about 1 mm over it. The oceanic crust itself is about 5 mm thick on this model.
 - . A tall volcanic peak from the Andes would measure about 6 mm above the surface at this scale. The ocean trench beside the continent would measure about 8 mm deep.
 - . Add dotted, blue lines parallel to the surface line at these heights above it for the atmospheric layers. Tropopause – 18 mm; stratopause – 50 mm; mesopause – 80 mm; thermopause – 480 mm.
8. Draw the boundaries between the layers and color the model. The boundaries are not smooth, but the one between the outer core and the lower mantle is especially wavy. This is the Gutenberg discontinuity. Your coloring scheme can include all colors, as it is hard to get enough shades of red-brown-orange-yellow to do each layer distinctively. After all, no one has been there to see. You may wish to use a light yellow on the inner core, and deeper orange one on the outer core. The ocean crust can be dark brown or black for its mafic minerals. The continental crust can be lighter, pinky brown for its felsic minerals. See page 4 for an example of labels for your model.

Resources for Earth systems science

I found **books** classified under a variety of Dewey catalog numbers – air quality (333.7), environmental problems (363.7); atmosphere (533.6 and 551.5); auroras (538.7+); water properties (546.2); general Earth science (550); geology, hydrology, and meteorology (551); economic geology (553); water cycle (551.48, 553.7); biomes (574.526); soil conservation (631.4, 574.5); physical geography (910.02).

Cattermole, Peter. 1995. ***Earth and Other Planets: Geology and Space Research***. Oxford University Press. ISBN 0-19-521138-3. [This has an extensive glossary and nice illustrations. See pages 108-109 for a good illustration to use on the “Slice of the Earth” model. UE-MS.]

Christopherson, Robert W. 1997. ***Geosystems: An Introduction to Physical Geology***. Prentice Hall. ISBN 0-13-505314-5. [This is an introductory college-level text with good diagrams and clear language. MS- adult]

Farndon, John. 1994. ***Dictionary of the Earth***. Dorling Kindersley. ISBN 0-7894-0049-9. [This is not a standard dictionary, but is more like an encyclopedia. The well-illustrated sections are arranged thematically. It would be a good report reference. UE-MS]

Gallant, Roy. 1998. ***Geysers: When the Earth Roars***. Franklin Watts. ISBN 0-531-158381 [This tells of an interaction between the lithosphere and hydrosphere. The underlying mechanisms are explained UE-MS]

Ganeri, Anita. 1994. ***The Ocean Atlas***. Dorling Kindersley. ISBN 1-56458-475-5. [This over-sized book has good illustrations of the ocean floors.]

Lamb, Simon, and David Sington. 1998. ***Earth Story: The Shaping of Our World***. Princeton University Press. ISBN 0-691-00229-0. [This book accompanies a BBC television series. Although it is MS-adult level, it has good tales to tell. The illustrations on pages 38-39 are helpful for the “Slice of the Earth” model.]

Shepard, Donna Walsh. 1995. ***Auroras: Light Shows in the Night Sky***. Franklin Watts. ISBN 0-531-20181-3. [The folklore and science of auroras. UE -read to LE.]

Van Rose, Susanna. 1994. ***Earth*** (Eyewitness Science) Dorling Kindersley. ISBN 1-56458-476-3. [This nicely illustrated book supplements studies of the lithosphere and hydrosphere. There are good photos of layered sand models of faults and mountain building.]

Walker, Sally M. 199X. ***Water Up, Water Down: The Hydrologic Cycle***. Carolrhoda Books. ISBN 0-87614-695-7. [This takes a good, thorough look at water, including groundwater, and sediment transport. UE-MS]

Internet resources

"Introduction to physical geography" lecture notes- good basic information with links to a glossary
<http://www.ouc.bc.ca/conted/onlinecourses/geog_111/111notes.html>

Information on the atmosphere and its layers <<http://www.shodor.org/metweb/session1/layers.html#troposphere>>

Basic information about the atmosphere for teachers

<<http://wings.ucdavis.edu:80/Book/Atmosphere/instructor/index.html>>

Who am I? Riddles of the atmosphere <<http://www.crpc.rice.edu/CRPC/GT/louviere/riddles.html>>

Earth systems education homepage, with links to pages on the spheres. <<http://ess.geology.ufl.edu/>>

Another Earth systems page <<http://www.cotf.edu/ete/modules/msese/earthsysflr/lithosphere.html>>

NOAA (National Oceanic and Atmospheric Administration) central library site, Wind and Sea, lists educational links
<<http://www.lib.noaa.gov/docs/windandsea.html>>

Resources available from the United States Geological Survey. Here are some materials well worth ordering from the USGS map store in Denver. **Posters** – “Landforms of the United States” (GI2206) [B&W, computer generated, great!]; “Geology of the Solar System” (GI 2596T) and “Mapping the Solar System” (GI 2447T) [Color, good for comparing Earth to other planets]; and “This Dynamic Planet” (GIA0023T) [Color, shows plates, earthquakes, and volcanoes.] There is an accompanying booklet – *This Dynamic Earth* (92-TDE) \$6.00. The booklet is available on the Internet at <<http://mapping.usgs.gov/mac/isb/pubs/factsheets/fs06899.html>>. This site has a more complete listing of the many educational materials available in printed or electronic form. The address is USGS Information Services, Box 25286, Denver, CO 80225. Phone 1-800-435-7627. The posters are \$4.00 each. There is a \$3.50 handling charge per order. They take Visa and MasterCard. Remember to ask for a list of free general interest publications.