Asteroids and Meteorites:

What is the difference between asteroids and meteorites? Asteroids are rocky and metallic objects that orbit the Sun but are too small to be considered planets. They are known as "minor planets". Asteroids range in size from Ceres, which has a diameter of about 1000 km, down to the size of pebbles. The term meteorite comes from the Greek *meteoron*, meaning "phenomenon in the sky", and it refers to any particle of solid matter that has fallen to Earth, the moon, or another planet, from space. Many meteorites originate as asteroids, others have origins from comets, and pieces of other planets in the solar system.

Studying meteorites is significant since other than rock samples collected from the moon, they are the only other direct samples of material from the solar system. Most have been unaltered since the early history of the solar system and using radiometric dating can provide constraints to its age. They provide information on the conditions and composition of the solar nebula, particularly for the inner planets (Mercury, Venus, Earth and Mars). They also help us to understand better the processes involved during planetary differentiation.

Most meteorites are the same age the solar system, 4.6 billion years old, but there is a special group (called SNC) which are 1.3 billions years old. There are three main categories of meteorites: Iron, Stony-Iron, and Stony. The stony meteorites are further divided into those which contain chondrules, Chondrites, and those which do not, Achondrites. Of the Chondrites, there are two main varieties: Ordinary and Carbonaceous. Now is a good time for you to examine some of the wonderful samples of meteorites held in Northwestern’s collection.

*Stony meteorites* have a similar composition to terrestrial ferromagnesian (Fe and Mg rich) silicates. *Chondrites* are composed of olivine and pyroxene rich *chondrules*, material that is believed to form at high temperatures, surrounded by a low temperature, fine grained matrix. *Carbonaceous Chondrites* are rich in volatile material (carbon) and they are undifferentiated, (meaning that they underwent no severe melting to segregate elements within them). Shown in Figure 1, they are similar in composition to our sun, hence thought to be of similar material which the solar nebula was originally composed. *Ordinary Chondrites* seem to show evidence that they formed in warmer parts of the solar nebula. They have undergone metamorphism, but they are undifferentiated, since this process would have destroyed the structure of the distinct chondrules in their matrices. *Achondrites* have a composition similar to lunar basalts, suggesting they formed as igneous magmas or impact melts. An absence of Fe in their composition suggests that they come from differentiate planetoids.

Figure 1.
Stony-Iron meteorites are made up of about half metal and half silicates. Their composition suggests that they come from intermediate depths in differentiated planetoids. Iron meteorites contain mostly Fe and some Ni, and they are thought to form at the center of large differentiated planetoids.

The different types of meteorites tell us much about geologic processes on and in planetary bodies. Most importantly, they give us information of whether or not they come from differentiated or undifferentiated bodies. The following table summarizes the discussion presented above:

### Types of Meteorites

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Abundance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>primarily iron and nickel structures within indicate very slow cooling regime, suggests they formed within a relatively large (300-1000km) sized planetoid similar to type M asteroids</td>
<td>5%</td>
</tr>
<tr>
<td>Stony Iron</td>
<td>mixtures of iron and stony material indicate that these come from intermediate depths in differentiated planetoids like type S asteroids</td>
<td>1%</td>
</tr>
<tr>
<td>Stony</td>
<td>Achondrite similar to terrestrial and lunar basalts, absence of Fe, suggesting that these come from differentiated planetoids a few are identical to moon rocks and SNC meteorites</td>
<td>94%</td>
</tr>
<tr>
<td>Chondrites</td>
<td>Ordinary have lost their light elements through high temperature metamorphism</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Carbonaceous very similar in composition to the Sun less volatiles similar to type C asteroids have light elements, including carbon</td>
<td>4%</td>
</tr>
</tbody>
</table>

Abundance*: percentages of each type of meteorite among all meteorites fallen on Earth

**Asteroids**

By the late 18th century it was recognized that the planets orbit at predictable distances from the sun, but no planet was found between Mars and Jupiter. The asteroid belt was later discovered orbiting in this region, and its locality leads to various theories for its formation. One theory suggests that it is the remains of a planet which was destroyed in a massive collision long ago. More likely, the asteroids represent material that never coalesced into a planet, possibly perturbed by Jupiter. If the estimated total mass from all asteroids were gathered together, it would form a body less than 1,500 kilometers (932 miles) across, which is less than half the diameter of our Moon.
Sizes, colors, and shapes of asteroids vary. The first asteroid discovered was Ceres and it is also the largest. It is classified as \textit{C-type}, which is the carbon-rich variety. Gaspra, Ida (both visited by Galileo spacecraft in 1991 and 1993, respectively), and Eros are classified as \textit{S-type}, composed of metal rich silicates. Other asteroids are classified as \textit{M-type}, composed mostly of Fe and Ni.

Asteroids have been found inside Earth’s orbit to beyond Saturn’s orbit. Most are contained within a zone between Mars and Jupiter, called \textit{Main Belt Asteroids}. Others, called \textit{Apollo Asteroids} and \textit{Near Earth Asteroids}, have highly elliptical orbits. These have a higher potential for collision with Earth and may be the source of much meteoritic material.

Figure 2 shows a possible theory for the origin of asteroids, as the source of the various types of meteorites. Here are some possible formation schemes:

A. an undifferentiated body of solar composition forms by accretion

B. a similar undifferentiated body of solar composition is heated (by radioactive decay) to the point of mild metamorphism, so that it loses some of its volatiles.

C-D. a planetary body is heated to the melting point of metallic iron, initiating differentiation. At this point, dense material would sink to the core, and lighter silicates rise to the crust and mantle.

At any point in these formation sequences, the planetary body could be broken apart (such as Figure 2 E) forming asteroid material which could later fall to earth as the various meteorites we observe.
Questions

i) What is the main difference between the two types of stony meteorites, chondrites and achondrites?

ii) Fill the blanks in the following summary using the names of different meteorites. *(hint, all of the names are in the table above)*

An original planetary body of solar nebula composition forms by accretion. If this is frozen in time and not differentiated, it could form ______________________________ meteorites.

If heating of a similar planetoid, causes mild metamorphism which drives off some volatiles but does not cause differentiation, ___________________________ meteorites could form.

If more intense heating of larger sized planetoid occurs this could cause differentiation. Iron (and heavy elements) would sink to form core where the lighter silicates form the mantles in the planetoids. A thin veneer of lava composed of the lightest silicates could erupt on the surface. If this planetoid is subjected to fragmentation (possibly resulting from impaction), the core components could form ___________________________ meteorites, core-mantle boundary sections, in addition to the mantle sections could form ___________________________ meteorites, and the extrusive igneous crustal sections (from the upper 10 km) could form ___________________________ meteorites. Thus fragmentation of differentiated or undifferentiated bodies could produce the spectrum of observed asteroid and meteorite types.

iii) Could a single planetoid give rise to all the various types of meteorites? Why?
iv) What sources of heat many have been important in the thermal evolution of planetoids?

v) Referring to the Table on page 2, what is the most abundant type of meteorite found on Earth? Using your knowledge of the conditions necessary to initiate planetary differentiation, speculate why these meteorites would be most abundant.

vi) What class of meteorites is most likely the core of Earth?