Meteorites

In general, meteorites are classified according to their structure and mineralogy.

Three very broad categories are recognized:
1. Stones
2. Irons
3. Stony-irons

See Table 1-3 for a listing of subcategories.

Stones (Stony)

- 94% of observed falls
- Thought to be material from mantle and crust areas of asteroids
- A few stone meteorites are believed to be from comets
- Stony meteorites contain approximately 75-90% silicate (stony) minerals (mostly olivine and pyroxene) and 10-25% nickel-iron metal and iron sulfide.
- In addition most stone meteorites contain varying degrees of nickel-iron alloy

Chondrites- Contain abundant, millimeter sized, rounded masses of pyroxene and olivine called chondrules
- Most likely formed from accreted solid material with a composition similar overall to that of our sun.

Achondrites- No chondrules (resemble igneous rocks from earth)

Carbonaceous chondrites- Contain abundant hydrocarbon, water and volatile elements (these also have a very different mineralogy compared to the ordinary chondrites. They contain hydrous minerals)
- The carbonaceous chondrites have volatile element abundances similar to the solar atmosphere (figure 1-8). It is believed that they formed at the same time and from the same material as the sun
- CCs with high amounts of refractory elements may represent the original material formed from the solar nebula. Most of the CCs represent late stages of the condensation process (must have been relatively cool to keep the volatile elements)
Irons
- Composed almost entirely of nickel-iron
- Often have mineral inclusions
- Believed to originate from the core of large asteroids

Stony-Irons
- Composed of approximately 50% nickel-iron and 50% silicate material
- Make up only 1 to 2% of all meteorites
- Core/mantle boundary?

Stellar evolution: Since the Sun is a pretty typical star, we will look at its composition in detail

From the figure above, we see four patterns that must be accounted for in any explanation for the origin of the elements:
1. An overwhelming abundance of light elements
2. A strong preference for even-numbered elements (see figure 1-10)
3. A peak in abundance at iron, followed by a steady decrease. (general decrease in abundance with increasing atomic number)
4. Elements 3-5, Lithium, Beryllium and Boron, are very low in abundance

Nucleosynthesis

A normal star like the Sun converts hydrogen into helium by a series of proton-proton collisions followed by emission of particles:
- Two hydrogen atoms collide to form deuterium (a H with a neutron)
- A deuterium captures a proton and becomes helium with two protons and one neutron
- Two of the helium atoms with two protons and one neutron combine to form a helium with two neutrons while releasing 2 protons

The Sun cannot make heavier elements than He. So where did the other elements come from?
From helium, there are two ways to get heavier nuclei:

1. We could add particles one at a time. However, all nuclei of mass 5 are extremely unstable.

2. Or we could collide helium atoms, except that all nuclei of mass 8 are also very unstable. However, when massive stars run low on hydrogen, they begin to collapse under their own gravity. Eventually, their interiors become so hot and dense that three-way collisions of helium nuclei can occur. The result is a nucleus with six protons and six neutrons (mass of 12), which is?

In still more massive stars, helium nuclei (alpha particles) collide with existing nuclei to make oxygen, neon, and so on.

(figure 1-11)

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So far we can explain #1, 2 and 4

- The abundance of light nuclei is due to the increasing difficulty of building heavier nuclei in stars.
- The preference for even numbers is the result of successive collisions of alpha particles (helium atoms). Odd-numbered elements form by collisions of single particles with nuclei.
- The jump from helium to carbon explains the rarity of lithium, beryllium and boron. These nuclei form by spallation - knocking pieces off heavier nuclei - and tend also to be destroyed by nuclear reactions in stars.

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The end result of fusion is iron, the most stable nucleus. Iron nuclei cannot yield energy either by fusion or fission. So where do even heavier nuclei come from?

- One way, the s-process (for slow) involves stray collisions between iron nuclei and other atomic particles. Obviously, the more particles added, the rarer the element will be.
- The other process is the r-process (for rapid). A massive star with a shell structure and an iron core might seem capable of eventually becoming solid iron as the shells migrate outward. It might, except for one thing: at some point the core becomes so massive its gravity overcomes the electrical repulsion between nuclei and the core collapses to become a neutron star, effectively a giant atomic nucleus.

Therefore, The abundance of iron is due to its being the most stable atomic nucleus.

The elements heavier than iron are built in massive old stars. The farther beyond iron they are, the rarer.

(# 3 is answered)
The chemical composition of the Earth, moon and planets

Jovian Planets (furthest from the sun): Jupiter, Saturn, Uranus and Neptune
Low masses and high densities (high gravity can hold in H and He)
These planets have gaseous H and He as well as "ices" made of volatile compounds such as H2O, CH4 and NH3)

Terrestrial Planets (closest to the sun): Mercury, Venus, Earth and Mars
High masses and low densities (gravity not strong enough to keep H and He and likely formed at higher temperatures)
These planets are all thought to have a core, mantle and crust similar to that of Earth

…and then there is Pluto…

The Earth’s crust

- The Transition Elements are very depleted relative to the earth as a whole and certain elements very much enriched, notably the alkali metals, lead, uranium, and some rare earths. The transition elements are largely in the Earth’s mantle and core.
- The enriched elements tend to be very large cations, especially those with large electrical charges (repeated partial melting of the mantle and accumulation of the residue in the crust).
- The mantle is mostly iron and magnesium silicates, ions with small sizes and electric charges of +2. Ions with large radii cannot fit mechanically very well into the mantle minerals and tend to leave at every opportunity. Ions with large electrical charges also require extensive substitution to be incorporated, and they also end up in the melt.

Comparison of the Earth composition with that of the moon

The Moon looks quite different from chondritic material and the continental crust. Hydrogen is enormously depleted, reflecting the almost total absence of water on the Moon. Among the metals, the right side of the Periodic Table is strongly depleted. These elements tend to be more volatile, and the Moon is strongly depleted in volatile materials. Generally, the lower the boiling point of an element, the lower its abundance on the Moon.