Question 1:

Dear Cheap Astronomy – Why do the gas giants have magnetic fields - aren't they mostly hydrogen?

A planetary magnetic field is generated by the organised motion of charged particles. The spiralling movement of those charged particles represents an electric current, which turns the planet into a giant electromagnet, which generates the giant magnetic field that surrounds it.

For example, Earth's magnetic field arises from the flow of liquid metals, mostly iron, within the molten part of the Earth's core. This flow of liquid metal is driven by the heat of the Earth's core, which creates a flow from the hotter inner regions to the cooler outer regions. This flow constantly circulates as material reaching the outer core cools and sinks back down again to be replaced by hotter material rising from below.

Added to this heat-driven circular flow is a lateral vector caused by the Earth's rotation. This organises the heat-driven circular flow into spiralling columns that are aligned with the Earth's axis of rotation.

This is why the Earth's magnetic poles are always roughly aligned with the Earth's geographic poles. The Earth's geographic poles indicate the position of the Earth's axis of rotation. The Earth's rotation around that axis organises the flow of the molten metals in the core into long spirals that run from north to south. Those long spirals of flowing molten metal act just like a coil of wire that has an electric current running through it. So, you get giant north-to-south electromagnets that direct lines of magnetic force out from around the Earth's north pole, which circle about the planet to be drawn back in around the south pole.

Those encircling lines of force represent the Earth's magnetic field, which is able to divert the paths of charged particles which might otherwise have collided with the Earth surface. Essentially the Earth's magnetic field donates energy to those charge particles to alter their trajectory, but because the energy of the Earth's magnetic field is being continually replenished this can go on for billions of years, as long as the inner Earth remains hot and molten and as long as the Earth keeps spinning.

The physics behind the magnetic fields of gas giants, like Jupiter and Saturn is very similar. Except in their case, it's not molten iron that's being whipped up into spiralling columns, but liquid hydrogen.

There are two ways to make liquid hydrogen – either cool it down to 33 Kelvin – or compress it within the core of a massive gas giant planet. If you form liquid hydrogen through such extreme compression, you get what we call metallic hydrogen, where the hydrogen becomes an electrical conductor.

It's because of this electrical conductivity that we call this state of hydrogen 'metallic'. Arguably, this is just sloppy terminology. Metals are not the only substances that can be conductive and being conductive isn't the only feature that defines a metal. But the name has stuck, so what the heck – it's metallic hydrogen.

Anyhow in a massive gas giant planet, hot metallic hydrogen acts just like the molten metals in the Earth's core, getting spun up into spiralling columns which form north-south aligned electromagnets, which then generate a powerful magnetic field around the planet.

Of course, in the Solar System the most humongously-powerful magnetic field of all is generated by the Sun. Within the Sun, hydrogen gets so hot that it becomes a plasma and, as a broiling hot and electrically-conductive plasma, it generates a much more dynamic and chaotic magnetic field than a planet does.

So magnetic lines of force can project out all over the Sun's surface in the form of sun spots. And sometimes those lines of force can get all twisted up and they may even break, which then flings out massive globs of hot hydrogen plasma that we call coronal mass ejections.

So… who said hydrogen isn't magnetic?

Question 2:

Dear Cheap Astronomy – Why does a gas giant like Jupiter produce so much radiation?

We've all heard how Jupiter is a scary place to visit because of all that radiation, which can slowly cook a spacecraft and its occupants. But just what kind of radiation are we talking about?

As far as electromagnetic radiation goes, Jupiter radiates more heat than it receives from the Sun, due to the gravitational compression of its, largely hydrogen, contents. However, this radiation is non-ionising – mainly in the infra-red and radio wavelengths and the vast majority of visible light from Jupiter is just reflected sunlight.

Any ionising electromagnetic radiation coming from the planet is largely the result of high-energy particle-to-particle interactions in the magnetosphere. This radiation comes from isolated point-sources, rather than it being global radiation. So, these radiation sources are unlikely to represent a significant risk to visiting spacecraft.

The 'dangerous' radiation that comes from Jupiter, is those high-energy particles themselves, so is not actually electromagnetic radiation at all. But, just like electromagnetic radiation at high-energies, these high-energy particles cause ionisation. When the particles collide with a material, they can knock electrons off the atoms of that material – indeed they can knock atomic nuclei out as well.

Once a nucleus is no longer in a stable relationship with its electrons, we just call it an ion, which is why the whole process is called ionisation. After ionisation, the sub-atomic particles produced carry a charge. The knocked-off ion has a positive charge, while the knocked-off electrons have a negative charge.

Now, you can protect your spacecraft from being ionised, with just a thin shield of metal. But this is only a temporary solution as surface of that shield will be slowly degraded over time as its atoms are steadily ionised

So, there you go. Jupiter's spacecraft-endangering radiation is actually high-energy particles – but it is still technically-correct to call this radiation. Before we fully understood the particle nature of radiation, we talked about radioactive decay producing alpha, beta and gamma radiation, all of which had different ionising effects. Alpha radiation turned out to be ions (mostly helium ions in those first laboratory experiments); while beta radiation was either high-energy electrons or high-energy positrons; and gamma radiation was, well, gamma radiation, or gamma rays – that is electromagnetic radiation in high-energy gamma wavelengths.

It turns out that the main source of the high-energy particles in Jupiter's so-called radiation belts is volcanic outgassing from its moon Io, which is the closest moon to Jupiter and which undergoes constant vulcanism due to all the tidal stretching it endures as it orbits close-in to the giant planet Jupiter. Io's volcanic outgassing is mostly sulphur and oxygen – and its mostly those atoms that dissociate into charged ions and electrons and which are then caught within Jupiter's magnetosphere. The rapidly-spinning planet's magnetic field then acts like a particle accelerator, whipping the particles up into high velocities and hence high energies.

The spacecraft Juno, which will arrive at Jupiter in August 2016, has most of its sensitive electronics shielded behind 1cm thick walls of titanium. Nonetheless, the spacecraft is only expected to last for about a year and the current plan is to de-orbit it into Jupiter around October 2017. Over that time, it will manage to do 33 polar orbits – and these will be highly-elliptical orbits that will bring it, at least once each orbit, right into Jupiter's radiation belts.

The Galileo spacecraft, which arrived at Jupiter in 1995, lasted 8 years, because it adopted a much wider orbit around Jupiter, largely avoiding the radiation belts. This allowed Galileo to conduct a series of fly-bys of to study the Galilean moons, that is, Io, Europa, Ganymede and Callisto. But with Juno, we are seeking to understand Jupiter the planet up close. So, we are going to slowly ionise a billion dollar spacecraft over the course of fourteen months – it's all in the name of science.