Bitesize Physics

Magnets – Very Small to Extremely Big

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We are quite right rightly concerned about the strength of the magnetic field before allowing personnel to enter our MRI scan rooms. Safety is always at the forefront of our minds and we religiously question and frisk our patients to ensure they are not going to come to any harm. But just how powerful are our magnets? Most of us will be using scanners with between 0.5 and 3 Tesla. A few will have less powerful open systems and some in research might be working with 7 Tesla, but how does this stack up compared with other magnets in existence?

Well did you know that your brain has a magnetic field? At about 1 picoTesla (0.000 000 000 001 Tesla it is not very strong but theorists claim it may have something to do with our consciousness. Certainly it is of no consequence to our everyday life and is not strong enough to prevent you losing your car keys by sticking them to your forehead.

Some of us are old enough to remember cassette players and video cassette recorders. They used magnetic tape of about 25 microTesla (0.000025 Tesla) to store sound, images or data. This was then read by running it past a reading head. Once again pretty weak but nonetheless a very successful and elegant solution, so long as your device didn't chew the tape up.

What about the earth's magnetic field? This varies depending a bit on where on the planet you are, but is about 50 microTesla (0.00005 Tesla) so again a reasonably low field strength, but one that is now large enough for us to perhaps envisage and observe the effects of, especially if you have used a compass to travel far enough north to witness the aurora borealis. If you are a pigeon, maybe it is even enough for you to find your way back to Bolton afterwards.

Anyone with children can these days barely locate their fridge/freezer behind an array of fridge magnets. These are in the order of 5 milliTesla (0.005 Tesla) and are strong enough for us to be able to feel the attraction when we hold it next to the fridge door, though it will probably fall off if used to hold up more than one sports day certificate.

But there are stronger magnets in the home. In the back of your stereo loudspeaker you will find a magnet used to drive soundwaves to your ear. It may surprise you to know that at 1 Tesla it is quite possibly as powerful as your MRI scanner. If you are into death metal you probably have a system that allows you to crank things up to crazy volumes. Such a system may have magnets up to 2.5 Tesla. This demonstrates very well that not only does the magnetic field strength play an important role in the attraction of a magnet, but also its mass. Think of the crane magnets used in scrap yards. These are also around 2 Tesla, but their size means that they can attract much heavier lumps of iron such as cars, or Jaws in The Spy Who Loved Me. They also have the advantage that they are electromagnets and so can be switched off to drop MOT failures into a crusher or oversized henchmen into a shark infested tank whilst you run around with scantily clad women..

A villain in peril

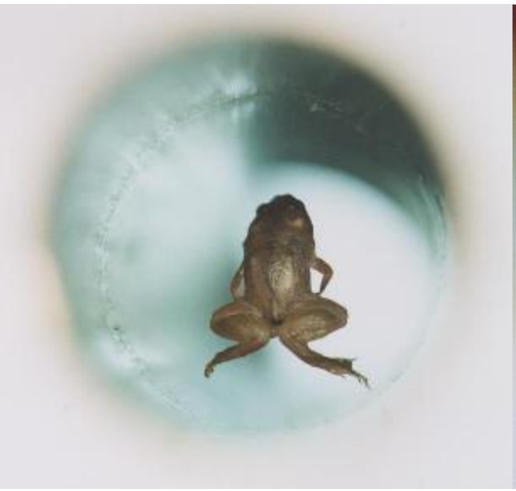
At somewhere around 5 Tesla we reach the field strength of the Magnetically Levitating (Maglev) trains. They travel along guideways using magnets to create both lift and propulsion, thereby reducing friction by a great extent and allowing very high speeds. They are very new, but already China, Japan and South Korea have them in commercial use. The Shanghai Maglev Train, also known as the Transrapid, is the fastest commercial train currently in operation and has a top speed of 430 km/h (270 mph). The line was designed to connect Shanghai Pudong International Airport and the outskirts of central Pudong, Shanghai, covering a distance of 30.5 kilometres (19.0 miles) in just 8 minutes.

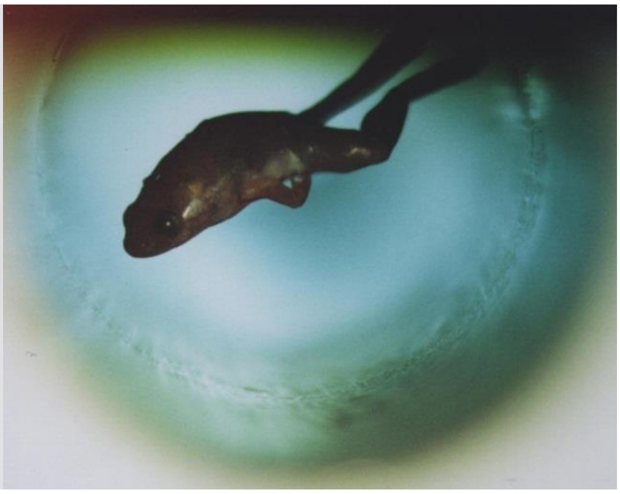
Maglevs in Beijing, Tokyo and Tel Aviv already under construction, but many other countries including the UK have demonstrated a great interest in the technology.

Shanghai Maglev

And so we have reached the kind of field strengths that we need to exercise some caution around and that we consider to be really powerful. But are they? And how far can we go? And what can we do with it?

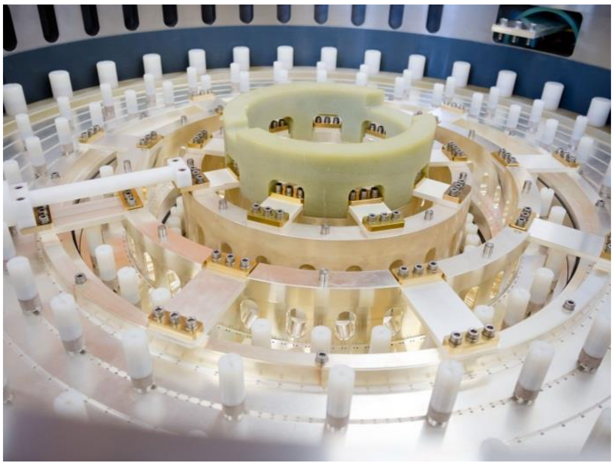
Well, now we start to get into the realms of research. We have reached the domain of men in white coats - real ale drinkers with beards and clipboards who find it amusing to levitate frogs (check Youtube) which incidentally can be done at 16 Tesla.





Kermit Maglev

The strongest field strength achieved by a resistive magnet is a massive 37.5 Tesla. This world record was taken by the High Field Magnet Laboratory in Nijmegen in March 2014. At only around £1million to construct it is over 10 times less expensive than similar strength hybrid systems. Much research is undertaken here including optical experiments, semiconductor work and nanotechnology. It is in here that Kermit enjoyed his flight.



High Field Magnet Laboratory in Nijmegen

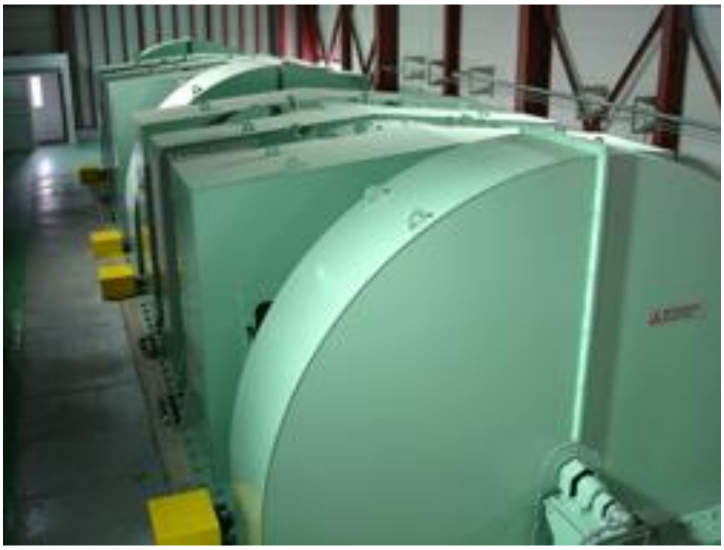
The National High Magnetic Field Laboratory in Talahassee in Florida State University has not only 14 large resistive magnets, but several hybrid magnets of which one holds the world record for such a unit at 45 Tesla. Hybrid systems use both a static magnet (in this case 33.5 Tesla) inside an electromagnetic insert (11.5 Tesla) and can maintain the field so long at the power is on. The research carried out here includes work into bio fuels for the future as well as MR imaging to learn more about HIV, Alzheimer's and Parkinson's. If you are in the area you can arrange a visit. From the website you can even click to request some magnet time but bear in mind the bore size is only 32mm before you think of using it for helping reduce your waiting list!

National High Magnetic Field Laboratory in Talahassee

But we are still not at the top. In New Mexico is the Los Alamos National Laboratory magnet which can reach 100 Tesla, but only for a few seconds. Their aim is to learn more about how materials behave when subjected to high fields. Immense stresses are placed on the coils such that they are at risk of destroying themselves. The energy that this would release would be so great that the building is evacuated whenever the magnet is switched activated.

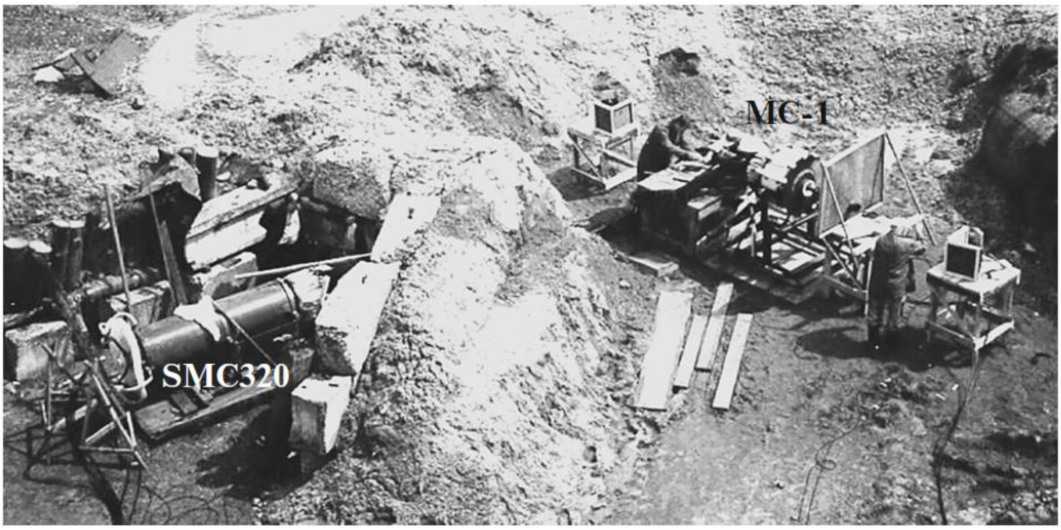
Get out of there man!

The strongest field ever produced in a laboratory is 730 Tesla by the Institute for Solid State Physics in Tokyo in its coolly named International MegaGauss Science Laboratory. It is not a machine that you should ever be fooled into bidding to own on ebay however as you would just get a box of nuts and bolts because the field causes the equipment to destroy itself when it is powered up.



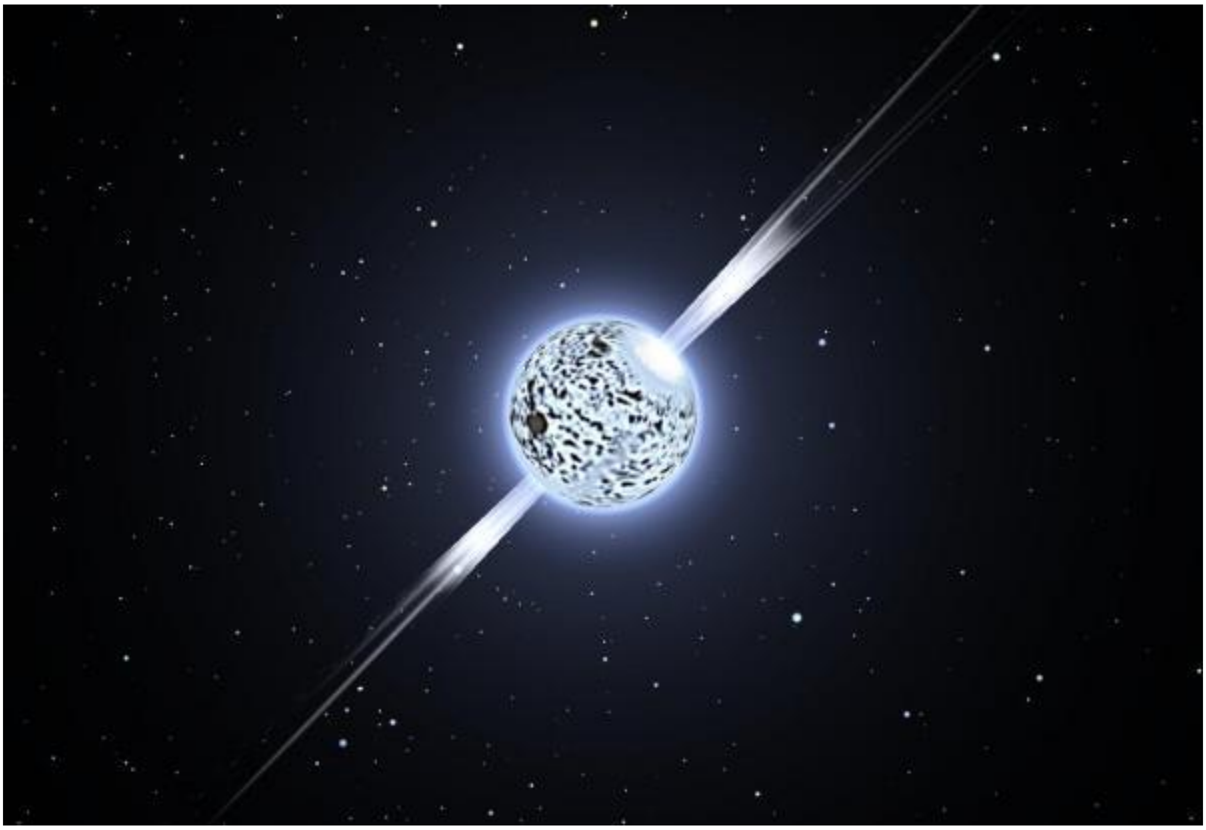
MegaGauss (Mega name!)

By using the MC-1 Generator in a laboratory in Russian Federal Nuclear Center, All-Russia Scientific Research Institute of Experimental Physics, Sarov, Russia, scientists used explosives to produce the strongest ever man-made pulsed field at 2800 Tesla. Once again the aim was to produce conditions where the properties of substances under extreme conditions can be observed, though from the picture it seems as you may have to venture into a quarry to do this.



The MC-1- Generator….really?

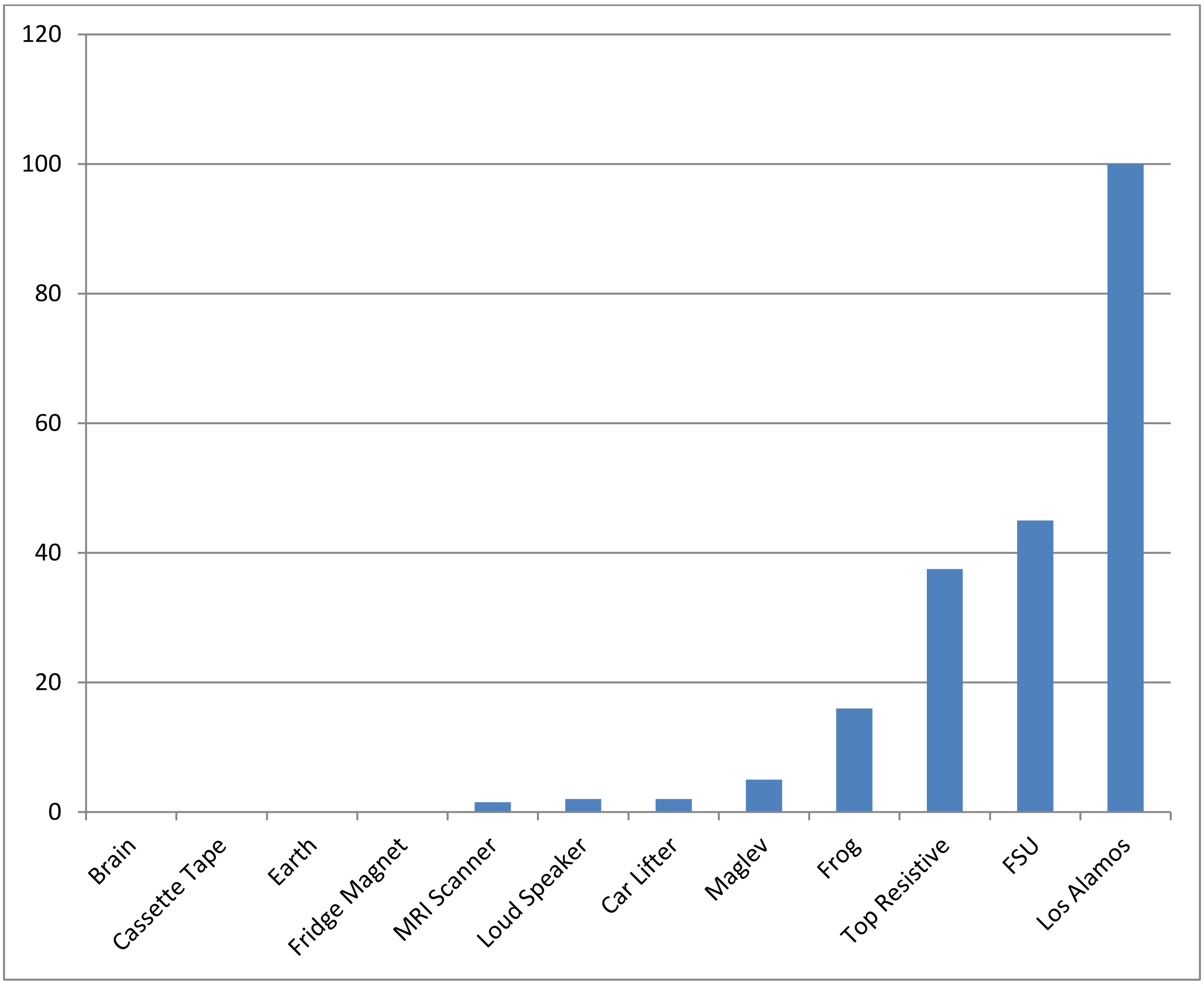
These are all massive fields by us earthlings standards, but nothing when you compare them to what is happening beyond our solar system. Consider a neutron star. These may only have a diameter of 10 miles or so, but are heavier that the sun. Putting this another way, if you collected a matchbox size of neutron star matter, you would need a big crane to lift it, as this small amount would weigh 5 trillion tons. All sounds rather incomprehensible, but we aren't done yet as just as amazingly, all this can be spinning at over 700 times per second. All this is combined with an incredible magnetic field of between 1 and 100 megaTesla (1000000 – 100000000 Tesla), so make sure you take your earrings out before visiting one. *'But it's hard enough getting an appointment for an MRI scan, let alone a neutron star!'* I hear your cry…well not really. Whilst there are only around 6 MRI scanners per million population in the UK, there is more than one neutron star each for us in our galaxy alone.



A Neutron star last week

But we are *still* not done yet. There is one last celestial body which holds the crown for the biggest magnet of them all, and what another great name – the Magnetar. They are types of neutron stars and are similarly sized such that you could walk right round one in an afternoon, that is if it didn't rip you to shreds whilst blasting you with copious gamma and x-rays. Their magnetic field is up to 100 gigaTesla (1000000000000 Tesla). This is so strong that if someone plonked one in southern Spain, it would kill everyone in London purely by ripping out all of their electrons such that they had no discernible atoms any more. Nice.

So that’s it. A collection of magnets covering quite a range of strengths. Below is a bar graph showing the relative field strengths of some of the magnets discussed in this article. However, the Tokyo MegaGauss, the Sarov MC and the neutron and magnetar have been left off as their inclusion would have scaled the others down into insignificance. You can include them mentally for yourself though. The bar for the MegaGauss would be around 1 metre long, whilst the MC-1 would stretch to around 30 metres. But this is nothing when you consider that you would need to draw a bar 100 kilometres for the neutron stars and up to 1000 kilometers for the magnetar.



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