THE MASS SPECTROMETER

This page describes how a mass spectrum is produced using a mass spectrometer.

How a mass spectrometer works

The basic principle

If something is moving and you subject it to a sideways force, instead of moving in a straight line, it will move in a curve - deflected out of its original path by the sideways force.

Suppose you had a cannonball travelling past you and you wanted to deflect it as it went by you. All you've got is a jet of water from a hose-pipe that you can squirt at it. Frankly, its not going to make a lot of difference! Because the cannonball is so heavy, it will hardly be deflected at all from its original course.

But suppose instead, you tried to deflect a table tennis ball travelling at the same speed as the cannonball using the same jet of water. Because this ball is so light, you will get a huge deflection.

The amount of deflection you will get for a given sideways force depends on the mass of the ball. If you knew the speed of the ball and the size of the force, you could calculate the mass of the ball if you knew what sort of curved path it was deflected through. The less the deflection, the heavier the ball.

Note: I'm not suggesting that you personally would have to do the calculation, although the maths isn't actually very difficult - certainly no more than A'level standard!

You can apply exactly the same principle to atomic sized particles.

An outline of what happens in a mass spectrometer

Atoms can be deflected by magnetic fields - provided the atom is first turned into an ion. Electrically charged particles are affected by a magnetic field although electrically neutral ones aren't.

The sequence is :

Stage 1: Ionisation

The atom is ionised by knocking one or more electrons off to give a positive ion. This is true even for things which you would normally expect to form negative ions (chlorine, for example) or never form ions at all (argon, for example). Mass spectrometers always work with positive ions.

Stage 2: Acceleration

The ions are accelerated so that they all have the same kinetic energy.

Stage 3: Deflection

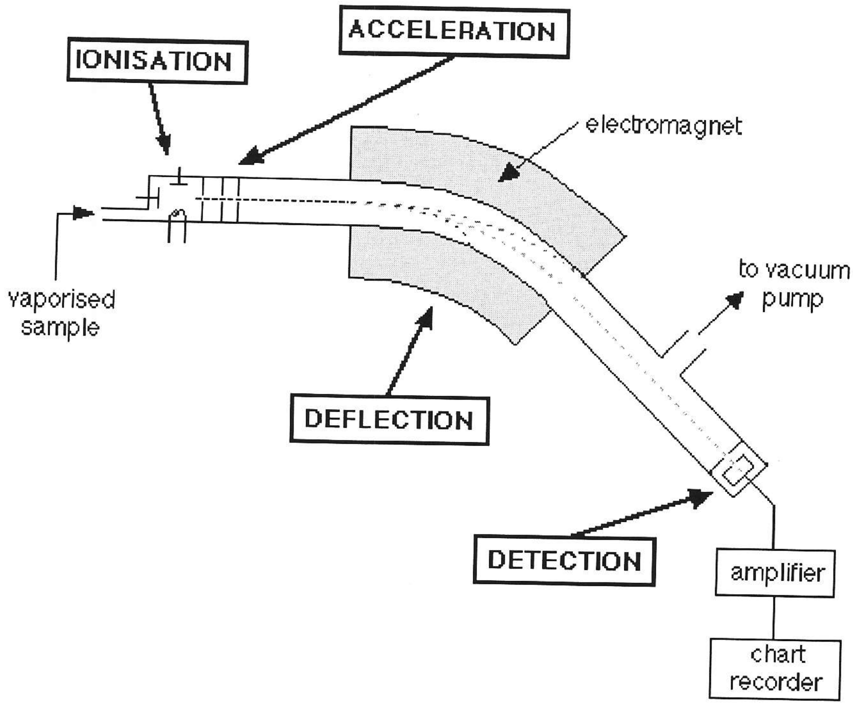
The ions are then deflected by a magnetic field according to their masses. The lighter they are, the more they are deflected.

The amount of deflection also depends on the number of positive charges on the ion - in other words, on how many electrons were knocked off in the first stage. The more the ion is charged, the more it gets deflected.

Stage 4: Detection

The beam of ions passing through the machine is detected electrically.

A full diagram of a mass spectrometer

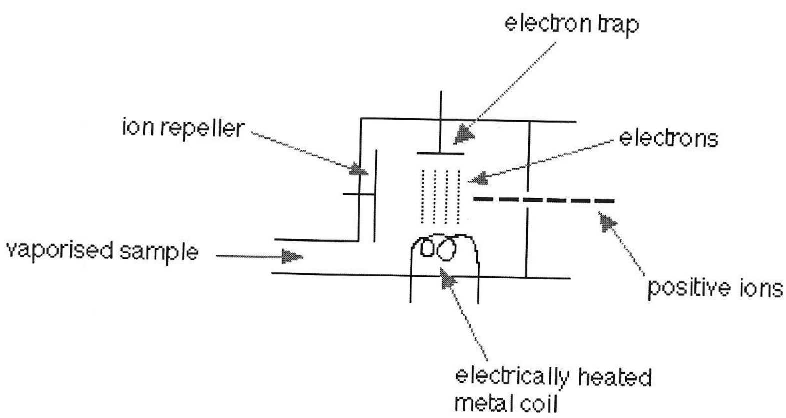


Understanding what's going on

The need for a vacuum

It's important that the ions produced in the ionisation chamber have a free run through the machine without hitting air molecules.

Ionisation



The vaporised sample passes into the ionisation chamber. The electrically heated metal coil gives off electrons which are attracted to the electron trap which is a positively charged plate.

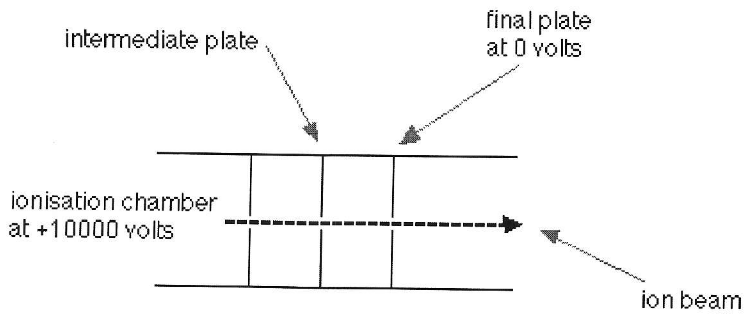
The particles in the sample (atoms or molecules) are therefore bombarded with a stream of electrons, and some of the collisions are energetic enough to knock one or more electrons out of the sample particles to make positive ions.

Most of the positive ions formed will carry a charge of +1 because it is much more difficult to remove further electrons from an already positive ion.

These positive ions are persuaded out into the rest of the machine by the ion repeller which is another metal plate carrying a slight positive charge.

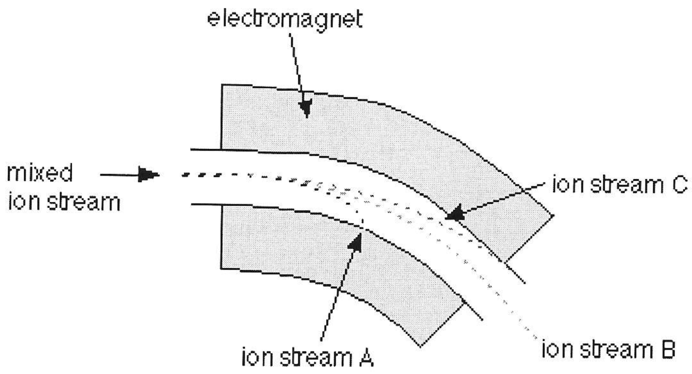
Note: As you will see in a moment, the whole ionisation chamber is held at a positive voltage of about 10,000 volts. Where we are talking about the two plates having positive charges, these charges are in addition to that 10,000 volts.

Acceleration



The positive ions are repelled away from the very positive ionisation chamber and pass through three slits, the final one of which is at 0 volts. The middle slit carries some intermediate voltage. All the ions are accelerated into a finely focused beam.

Deflection



Different ions are deflected by the magnetic field by different amounts. The amount of deflection depends on:

- the mass of the ion. Lighter ions are deflected more than heavier ones.
- the charge on the ion. Ions with 2 (or more) positive charges are deflected more than ones with only 1 positive charge.

These two factors are combined into the ***mass/charge ratio.*** Mass/charge ratio is given the symbol m/z (or sometimes m/e).

For example, if an ion had a mass of 28 and a charge of 1+, its mass/charge ratio would be 28. An ion with a mass of 56 and a charge of 2+ would also have a mass/charge ratio of 28.

In the last diagram, ion stream A is most deflected - it will contain ions with the smallest mass/charge ratio. Ion stream C is the least deflected - it contains ions with the greatest mass/charge ratio.

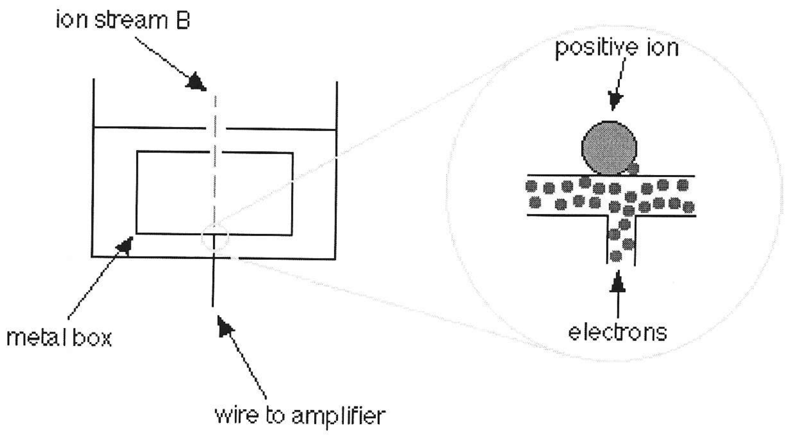
It makes it simpler to talk about this if we assume that the charge on all the ions is 1+. Most of the ions passing through the mass spectrometer will have a charge of 1+, so that the mass/charge ratio will be the same as the mass of the ion.

Note: You must be aware of the possibility of 2+ (etc) ions, but the vast majority of A'level questions will give you mass spectra which only involve 1+ ions. Unless there is some hint in the question, you can reasonably assume that the ions you are talking about will have a charge of 1+.

Assuming 1+ ions, stream A has the lightest ions, stream B the next lightest and stream C the heaviest. Lighter ions are going to be more deflected than heavy ones.

Detection

Only ion stream B makes it right through the machine to the ion detector. The other ions collide with the walls where they will pick up electrons and be neutralised. Eventually, they get removed from the mass spectrometer by the vacuum pump.



When an ion hits the metal box, its charge is neutralised by an electron jumping from the metal on to the ion (right hand diagram). That leaves a space amongst the electrons in the metal, and the electrons in the wire shuffle along to fill it.

A flow of electrons in the wire is detected as an electric current which can be amplified and recorded. The more ions arriving, the greater the current.

Detecting the other ions

How might the other ions be detected - those in streams A and C which have been lost in the machine?

Remember that stream A was most deflected - it has the smallest value of m/z (the lightest ions if the charge is 1+). To bring them on to the detector, you would need to deflect them less - by using a smaller magnetic field (a smaller sideways force).

To bring those with a larger m/z value (the heavier ions if the charge is +1) on to the detector you would have to deflect them more by using a larger magnetic field.

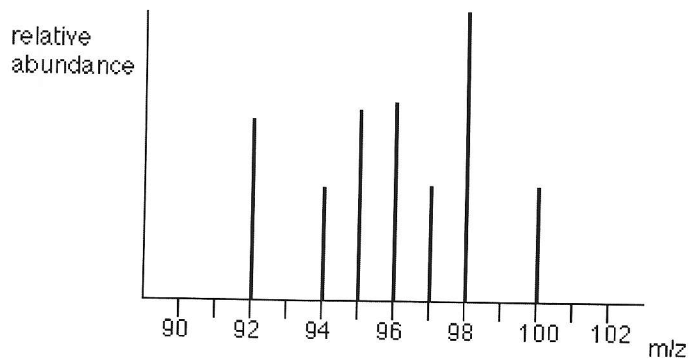
If you vary the magnetic field, you can bring each ion stream in turn on to the detector to produce a current which is proportional to the number of ions arriving. The mass of each ion being detected is related to the size of the magnetic field used to bring it on to the detector. The machine can be calibrated to record current (which is a measure of the number of ions) against m/z directly. The mass is measured on the ^{12}C scale.

Note: The ^{12}C scale is a scale on which the ^{12}C isotope weighs exactly 12 units.

What the mass spectrometer output looks like

The output from the chart recorder is usually simplified into a "stick diagram". This shows the relative current produced by ions of varying mass/charge ratio.

The stick diagram for molybdenum looks lilke this:



You may find diagrams in which the vertical axis is labelled as either "relative abundance" or "relative intensity". Whichever is used, it means the same thing. The vertical scale is related to the current received by the chart recorder - and so to the number of ions arriving at the detector: the greater the current, the more abundant the ion.

As you will see from the diagram, the commonest ion has a mass/charge ratio of 98. Other ions have mass/charge ratios of 92, 94, 95, 96, 97 and 100.

That means that molybdenum consists of 7 different isotopes. Assuming that the ions all have a charge of 1+, that means that the masses of the 7 isotopes on the carbon-12 scale are 92, 94, 95, 96, 97, 98 and 100.

Note: If there were also 2+ ions present, you would know because every one of the lines in the stick diagram would have another line at exactly half its m/z value (because, for example, 98/2 = 49). Those lines would be much less tall than the 1+ ion lines because the chances of forming 2+ ions are much less than forming 1+ ions.

If you want to go straight on to how you use these mass spectra to calculate relative atomic masses you can jump straight to that page by following this link rather than going via the menus below.

Where would you like to go now?

To the mass spectrometry menu . . .

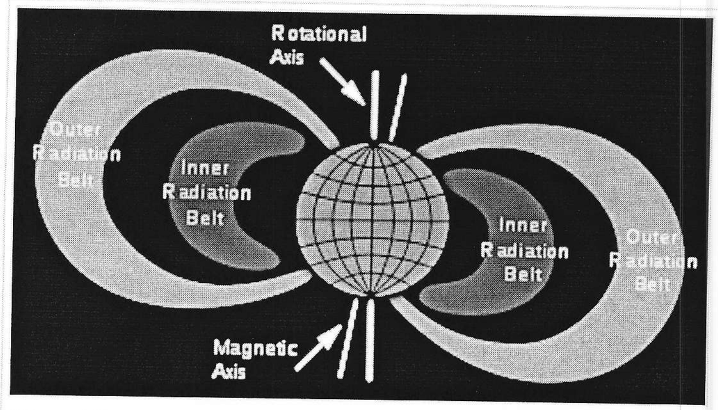
To the instrumental analysis menu . . .

To Main Menu . . .

Found this page useful? **Hate** chemistry calculations? You need help!

Van Allen radiation belt

From Wikipedia, the free encyclopedia



Van Allen radiation belts

The **Van Allen radiation belt** is a torus of energetic charged particles (plasma) around Earth, which is held in place by Earth's magnetic field. It is thought that most of the particles that form the belts come from solar wind, and other particles by cosmic rays.[1] It is named after its discoverer, James Van Allen, and is located in the inner region of the Earth's magnetosphere. It is split into two distinct belts, with energetic electrons forming the outer belt and a combination of protons and electrons forming the inner belts. In addition, the radiation belts contain lesser amounts of other nuclei, such as alpha particles. The belts pose a hazard to satellites, which must protect their sensitive components with adequate shielding if their orbit spends significant time in the radiation belts.

Contents

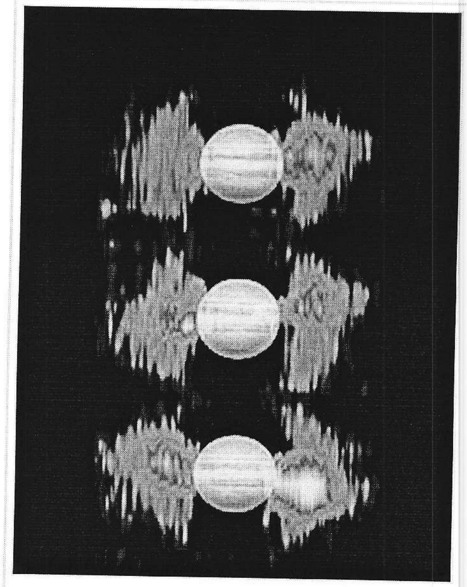
Discovery

Prior to the Space Age, the possibility of trapped charged particles had been investigated by Kristian Birkeland, Carl Stormer, and Nicholas Christofilos.[2] The existence of the belt was confirmed by the Explorer 1 and Explorer 3 missions in early 1958, under Dr. James Van Allen at the University of Iowa. The trapped radiation was first mapped out by Explorer 4, Pioneer 3 and Luna 1.

The term *Van Allen belts* refers specifically to the radiation belts surrounding Earth; however, similar radiation belts have been discovered around other planets. The Sun itself does not support long-term radiation belts, as it lacks a stable, global dipole field. The Earth's atmosphere limits the belts' particles to regions above 200–1,000 km,[3] while the belts do not extend past 7 Earth radii R_E.[3] The belts are confined to an area which extends about 65°[3] from the celestial equator.

Research

An upcoming NASA mission, Radiation Belt Storm Probes (RBSP), will go further and gain scientific understanding (to the point of predictability) of how populations of relativistic electrons and ions in space form or change in response to changes in solar activity and the solar wind.



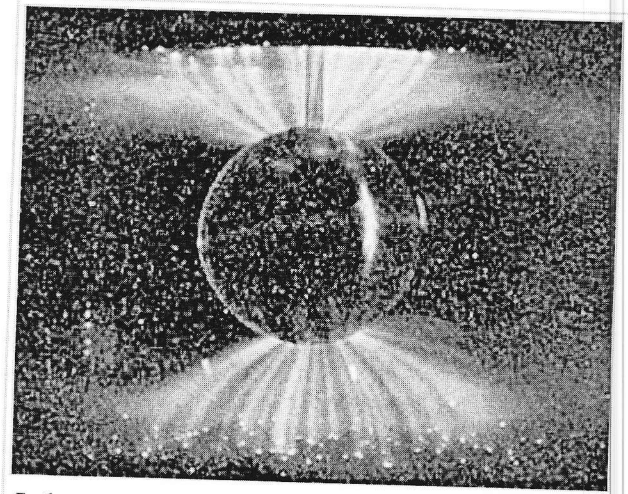
Jupiter's variable radiation belts

The RBSP mission is currently scheduled for 2012. The primary mission is scheduled to last 2 years, with expendables expected to last for 4 years. NASA's Goddard Space Flight Center manages the overall Living With a Star program of which RBSP is a project, along with Solar Dynamics Observatory (SDO). The Applied Physics Laboratory is responsible for the overall implementation and instrument management for RBSP.[4]

Van Allen radiation belts do exist on other planets in the solar system, whenever a planet or moon has a magnetic field that is powerful enough to sustain a radiation belt. However, many of these radiation belts have been poorly mapped. The Voyager Program (namely Voyager 2) only nominally confirmed the existence of similar belts on Uranus and Neptune.

Outer belt

The large outer radiation belt extends from an altitude of about three to ten Earth radii (R_E) or 13,000 to 60,000 kilometres above the Earth's surface. Its greatest intensity is usually around 4–5 R_E. The outer electron radiation belt is mostly produced by the inward radial diffusion[5][6] and local acceleration[7] due to transfer of energy from whistler mode plasma waves to radiation belt electrons. Radiation belt electrons are also constantly removed by collisions with atmospheric neutrals,[7] losses to magnetopause, and the outward radial diffusion. The outer belt consists mainly of high energy (0.1–10 MeV) electrons trapped by the Earth's magnetosphere. The gyroradii for energetic protons would be large enough to bring them into contact with the Earth's atmosphere. The electrons here have a high flux and at the outer edge (close to the magnetopause), where geomagnetic field lines open into the geomagnetic "tail", fluxes of energetic electrons can drop to the low interplanetary levels within about 100 km (a decrease by a factor of 1,000).


Laboratory simulation of the Van Allen belt's influence on the Solar Wind; these aurora-like Birkeland currents were created by the scientist Kristian Birkeland in his terrella, a magnetized anode globe in an evacuated chamber.

The trapped particle population of the outer belt is varied, containing electrons and various ions. Most of the ions are in the form of energetic protons, but a certain percentage are alpha particles and O^+ oxygen ions, similar to those in the ionosphere but much more energetic. This mixture of ions suggests that ring current particles probably come from more than one source.

The outer belt is larger than the inner belt and its particle population fluctuates widely. Energetic (radiation) particle fluxes can increase and decrease dramatically as a consequence of geomagnetic storms, which are themselves triggered by magnetic field and plasma disturbances produced by the Sun. The increases are due to storm-related injections and acceleration of particles from the tail of the magnetosphere.

There is debate as to whether the outer belt was discovered by the United States Explorer 4 or the USSR Sputnik 2/3.[*citation needed*]

Inner belt

While protons form one radiation belt, trapped electrons present two distinct structures, the inner and outer belt. The inner electron Van Allen Belt extends typically from an altitude of 1.2 to 3 Earth radii (L values of 1 to 3).[8] In certain cases when solar activity is stronger or in geographical areas such as the South Atlantic Anomaly (SAA), the inner boundary may go down to a few hundred kilometers[9] above the Earth's surface. The inner belt contains high concentrations of electrons in the range of hundreds of keV and energetic protons with energies exceeding 100 MeV, trapped by the strong (relative to the outer belts) magnetic fields in the region. [10]

It is believed that proton energies exceeding 50 MeV in the lower belts at lower altitudes are the result of the beta decay of neutrons created by cosmic ray collisions with nuclei of the upper atmosphere. The source of lower energy protons is believed to be proton diffusion due to changes in the magnetic field during geomagnetic storms.[11]

Due to the slight offset of the belts from Earth's geometric center, the inner Van Allen belt makes its closest approach to the surface at the South Atlantic Anomaly.[12] [13]

Flux values

In the belts, at a given point, the flux of particles of a given energy decreases sharply with energy.

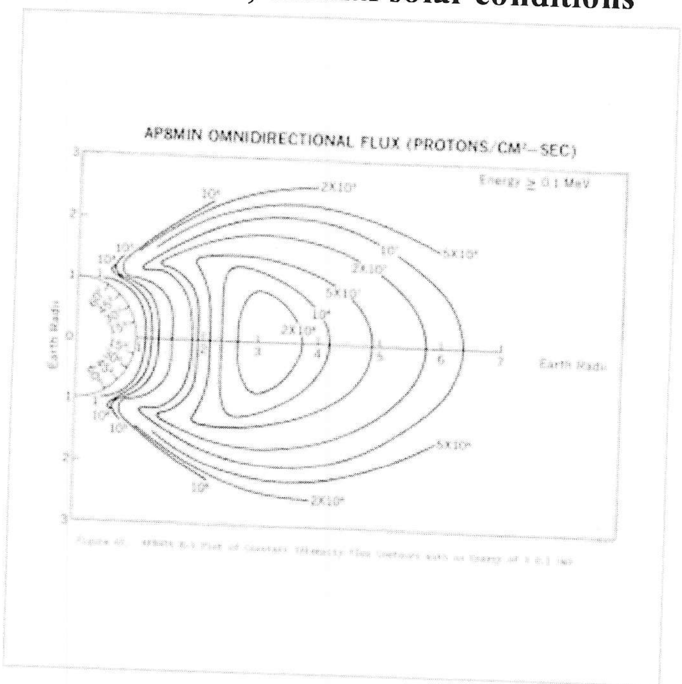
At the magnetic equator, electrons of energies exceeding 500 keV (resp. 5 MeV) have omnidirectional fluxes ranging from 1.2×10^6 (resp. 3.7×10^4) up to 9.4×10^9 (resp. 2×10^7) particles per square centimeter per second.

The proton belts contain protons with kinetic energies ranging from about 100 keV (which can penetrate 0.6 microns of lead) to over 400 MeV (which can penetrate 143 mm of lead).[14]

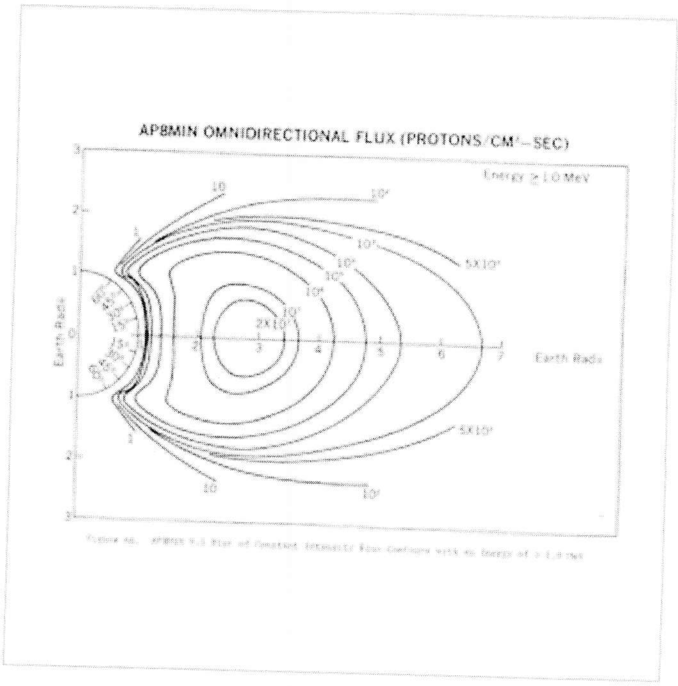
Most published flux values for the inner and outer belts may not show the maximum probable flux densities that are possible in the belts. There is a reason for this discrepancy: the flux density and the location of the peak flux is variable (depending primarily on solar activity), and the number of spacecraft with instruments observing the belt in real time has been limited. The Earth has not experienced a solar storm of Carrington event intensity and duration while spacecraft with the proper instruments have been available to observe the event.

Regardless of the differences of the flux levels in the Inner and Outer Van Allen belts, the beta radiation levels would be dangerous to humans if they were exposed for an extended period of time.[12][15]

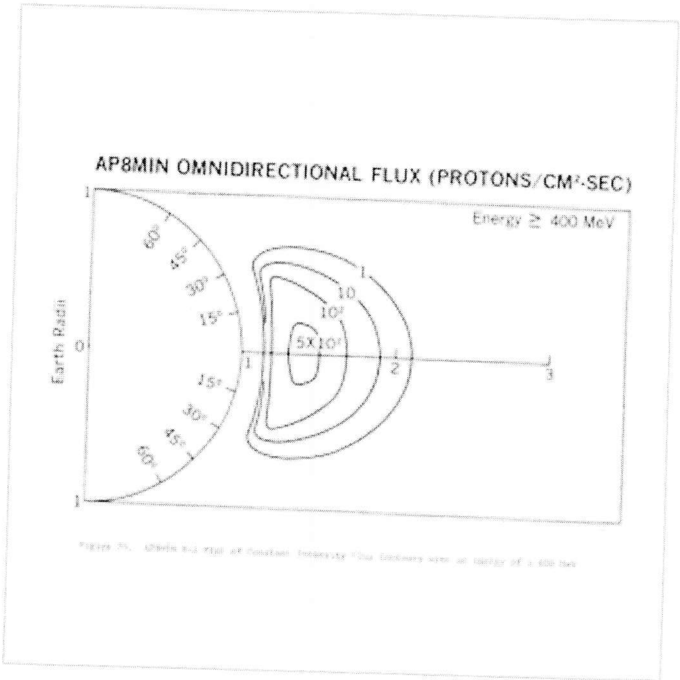
Flux values, normal solar conditions



AP8 MIN omnidirectional proton flux >=100keV



AP8 MIN omnidirectional proton flux >=1MeV



AP8 MIN omnidirectional proton flux >=400MeV

Antimatter confinement

In 2011, a study has confirmed earlier speculation that the Van Allen belt could confine antiparticles. The PAMELA experiment detected orders of magnitude higher levels of antiprotons than are expected from normal particle decays while passing through the SAA. This suggests the van Allen belts confine a significant flux of antiprotons produced by the interaction of the Earth's upper atmosphere with cosmic rays.[16] The energy of the antiprotons has been measured in the range from 60 - 750 MeV.

Implications for space travel

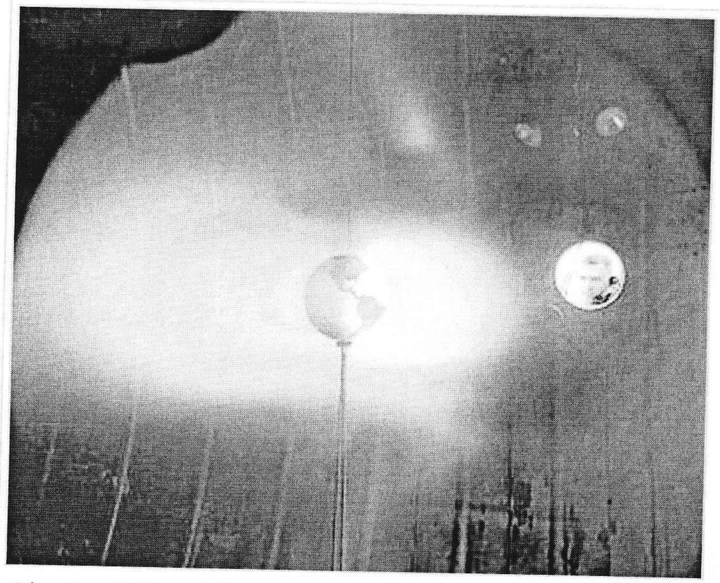
Missions beyond low earth orbit leave the protection of the geomagnetic field, and transit the Van Allen belts. Thus they may need to be shielded against exposure to cosmic rays, Van Allen radiation, or solar flares. The region between two to four earth radii lies between the two radiation belts and is sometimes referred to as the "safe zone".[17][18]

Solar cells, integrated circuits, and sensors can be damaged by radiation. Geomagnetic storms occasionally damage electronic components on spacecraft. Miniaturization and digitization of electronics and logic circuits have made satellites more vulnerable to radiation, as the total charge in these circuits is now small enough so as to be comparable with the charge of incoming ions. Electronics on satellites must be hardened against radiation to operate reliably. The Hubble Space Telescope, among other satellites, often has its sensors turned off when passing through regions of intense radiation.[19] A satellite shielded by 3 mm of aluminium in an elliptic orbit (200 by 20,000 miles) passing through the radiation belts will receive about 2,500 rem (25 Sv) per year. Almost all radiation will be received while passing the inner belt.[20]

The Apollo astronauts traveled through the Van Allen radiation belts on the way to the Moon; however, exposure was minimized by following a trajectory along the edge of the belts that avoided the strongest areas of radiation.[21] The total radiation exposure to astronauts was estimated to be much less than the five (5) rem set by the U.S. Atomic Energy Commission for people who work with radioactivity.[22]

Causes

It is generally understood that the inner and outer Van Allen belts result from different processes. The inner belt, consisting mainly of energetic protons, is the product of the decay of so-called "albedo" neutrons which are themselves the result of cosmic ray collisions in the upper atmosphere. The outer belt consists mainly of electrons. They are injected from the geomagnetic tail following geomagnetic storms, and are subsequently energized though wave-particle interactions.



Simulated Van Allen Belts generated by a plasma thruster

In the inner belt, particles are trapped in the Earth's nonlinear magnetic field. Particles gyrate and move along field lines radiating energy in the form of gamma rays. As particles encounter regions of larger density of magnetic field lines, their "longitudinal" velocity is slowed and can be reversed, reflecting the particle, radiating energy and producing aurora borialis. This causes the particle to bounce back and forth between the Earth's poles, losing all its energy.[23] Globally, the motion of this trapped particles is chaotic. [24] The effect of these planetary magnetic fields is to protect planets from the outer space radiation.

in tank #5 Electric Propulsion Laboratory at the then-called Lewis Research Center, Cleveland, Ohio.

A gap between the inner and outer Van Allen belts, sometimes called safe zone or safe slot, is caused by the Very Low Frequency (VLF) waves which scatter particles in pitch angle which results in the gain of particles to the atmosphere. Solar outbursts can pump particles into the gap but they drain again in a matter of days. The radio waves were originally thought to be generated by turbulence in the radiation belts, but recent work by James Green of the NASA Goddard Space Flight Center comparing maps of lightning activity collected by the Micro Lab 1 spacecraft with data on radio waves in the radiation-belt gap from the IMAGE spacecraft suggests that they are actually generated by lightning within Earth's atmosphere. The radio waves they generate strike the ionosphere at the right angle to pass through it only at high latitudes, where the lower ends of the gap approach the upper atmosphere. These results are still under scientific debate.

There have been nuclear tests in space that have caused artificial radiation belts. Starfish Prime, a high altitude nuclear test, created an artificial radiation belt that damaged or destroyed as many as one third of the satellites in low earth orbit at the time.

Removal

The belts are a hazard for artificial satellites and are moderately dangerous for human beings, but are difficult and expensive to shield against.

The Russian physicist V.V. Danilov proposed the use of a High Voltage Orbiting Long Tether as a potential means to drain the radiation belt of high energy particles. The proposal involves deploying highly electrically charged tethers from satellites in orbit. Charged particles within the radiation belt encountering these tethers would be deflected by their large electrostatic fields onto paths that intersect with the atmosphere, where they would be harmlessly dissipated.[25] Simulations have suggested that the inner belt could be drained to 1% of its natural electron flux within two months of HiVOLT operation.[26]

See also

- L-shell
- List of artificial radiation belts
- List of plasma (physics) articles
- Space weather

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External links

- An explanation of the belts (http://www.phy6.org/Education/Iradbelt.html)
- Trapped particle radiation models (http://www.spenvis.oma.be/spenvis/help/background/traprad/traprad.html) — Introduction to the Trapped Radiation Belts.
- SPENVIS - Space Environment, Effects, and Education System (http://www.spenvis.oma.be/) —Gateway to the SPENVIS orbital dose calculation software.

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Categories: Geomagnetism | Space plasmas

? Ask an Astrophysicist

The Question

(Submitted February 28, 1997)

I wonder if you could tell me exactly what the VAN ALLEN BELT is and how much radiation does it contain, ie how many rems of radiation are there out there? Plus, what protection would organic life need to be protected from this radiation?

The Answer

David Stern, a researcher in another lab here at Goddard, has graciously supplied an answer to your question, given below:

"The **radiation belts** are regions of high-energy particles, mainly protons and **electrons**, held captive by the magnetic influence of the Earth. They have two main sources. A small but very intense "inner belt" (some call it "The Van Allen Belt" because it was discovered in 1958 by James Van Allen of the University of Iowa) is trapped within 4000 miles or or so of the Earth's surface. It consists mainly a high-energy **protons** (10-50 MeV) and is a by-product of the cosmic radiation, a thin drizzle of very fast protons and nuclei which apparently fill all our galaxy.

" In addition there exist electrons and protons (and also oxygen particles from the upper **atmosphere**) given moderate energies (say 1-100 keV; 1 MeV = 1000 keV) by processes inside the domain of the Earth's **magnetic field**. Some of these electrons produce the polar aurora ("northern lights") when they hit the upper atmosphere, but many get trapped, and among those, protons and positive particles have most of the energy .

"I looked up a typical **satellite** passing the radiation belts (elliptic **orbit**, 200 miles to 20000 miles) and the radiation dosage per year is about 2500 rem, assuming one is shielded by 1 gr/cm-square of aluminum (about 1/8" thick plate) almost all of it while passing the inner belt. But there is no danger. The way the particles move in the magnetic field prevents them from hitting the atmosphere, and even if they are scattered so their orbit does intersect the ground, the atmosphere absorbs them long before they get very far. Even the space station would be safe, because the orbits usually stop above it--any particles dipping deeper down are lost much faster than they can be replenished.

"If all this sounds too technical but you still want to find out-- what ions and magnetic fields and **cosmic rays** are, etc.--you will find a long detailed exposition (both without math) on the World Wide Web at: **http://www.phy6.org/Education/Intro.html**

Good luck!

David Stern

Note:

Another point of particular interest to us in high-energy astrophysics is the South Atlantic Anomaly. This is a region of very high particle **flux** about 250 km above the Atlantic Ocean off the coast of Brazil and is a result of the fact that the Earth's rotational and magnetic axes are not aligned (see **http://heasarc.nasa.gov/docs/rosat/gallery/display/saa.html**). The particle flux is so high in this region that often the detectors on our satellites must be shut off (or at least placed in a "safe" mode) to protect them from the radiation.

Andy Ptak
for Ask an Astrophysicist

Questions on this topic are no longer responded to by the "Ask an Astrophysicist" service. See http://imagine.gsfc.nasa.gov/docs/ask_astro/ask_an_astronomer.html for help on other astronomy Q&A services.

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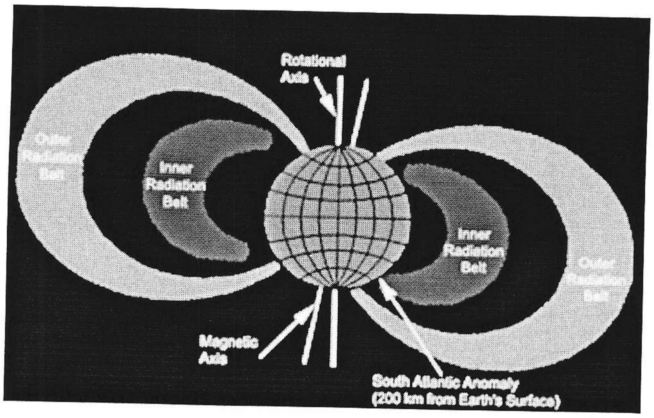
Van Allen Radiation Belt



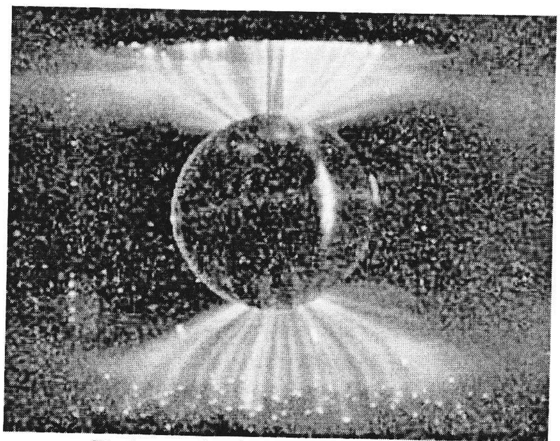
The Van Allen radiation belt is a torus of energetic charged particles (i.e. a plasma) around Earth, trapped by Earth's magnetic field. The Van Allen belts are closely related to the polar aurora where particles strike the upper atmosphere and fluoresce. The presence of a radiation belt had been theorized prior to the Space Age and the belt's presence was confirmed by the Explorer I on January 31, 1958 and Explorer III missions, under Doctor James Van Allen.

The trapped radiation was first mapped out by Explorer IV and Pioneer III.Qualitatively, it is very useful to view this belt as consisting of two belts around Earth, the inner radiation belt and the outer radiation belt. The particles are distributed such that the inner belt consists mostly of protons while the outer belt consists mostly of electrons. Within these belts are particles capable of penetrating about 1 g/cm2 of shielding (e.g., 1 millimetre of lead).

The term 'Van Allen Belts' refers specifically to the radiation belts surrounding Earth; however, similar radiation belts have been discovered around other planets. The Sun does not support long-term radiation belts.

The Earth's atmosphere limits the belts' particles to regions above 200-1000 km, while the belts do not extend past 7 Earth radii RE. The belts are confined to an area which extends about 65� from the celestial equator.

The Outer Van Allen Belt



Enlarged View of this image

The big outer radiation belt extends from an altitude of about 10,000�65,000 km and has its greatest intensity between 14,500�19,000 km. The outer belt is thought to consist of plasma trapped by the Earth's magnetosphere. The USSR's Luna 1 reported that there were very few particles of high energy within the outer belt. The gyroradii for energetic protons would be large enough to bring them into contact with the Earth's atmosphere. The electrons here have a high flux and along the outer edge and electrons with kinetic energy E > 40 keV can drop to normal interplanetary levels within about 100 km (a decrease by a factor of 1000). This drop-off is a result of the solar wind.

The particle population of the outer belt is varied, containing electrons and various ions. Most of the ions are in the form of energetic protons, but a certain percentage are alpha particles and O+ oxygen ions, similar to those in the ionosphere but much more energetic. This mixture of ions suggests that ring current particles probably come from more than one source.

The outer belt is larger and more diffused than the inner, surrounded by a low-intensity region known as the ring current. Unlike the inner belt, the outer belt's particle population fluctuates widely and is generally weaker in intensity (less than 1 MeV), rising when magnetic storms inject fresh particles from the tail of the magnetosphere, and then falling off again.

There is debate as to whether the outer belt was discovered by the US Explorer IV or the USSR Sputnik II/III.

The Inner Van Allen Belt

The inner Van Allen Belt extends from roughly 1.1 to 3.3 Earth radii, and contains high concentrations of energetic protons with energies exceeding 100 MeV, trapped by the strong (relative to the outer belts) magnetic fields in the region.

It is believed that protons of energies exceeding 50 MeV in the lower belts at lower altitudes are the result of the beta decay of cosmic ray neutrons. The source of lower energy protons is believed to be proton diffusion due to changes in the magnetic field during geomagnetic storms.

The Van Allen Belt's Impact on Space Travel

Solar cells, integrated circuits, and sensors can be damaged by radiation. In 1962, the Van Allen belts were temporarily amplified by a high-altitude nuclear explosion (the Starfish Prime test) and several satellites ceased operation.

Magnetic storms occasionally damage electronic components on spacecraft. Miniaturization and digitization of electronics and logic circuits have made satellites more vulnerable to radiation, as incoming ions may be as large as the circuit's charge. Electronics on satellites must be hardened against radiation to operate reliably.

The Hubble Space Telescope, among other satellites, often has its sensors turned off when passing through regions of intense radiation. An object satellite shielded by 3 mm of aluminum will receive about 2500 rem (25 Sv) per year.

Proponents of the Apollo Moon Landing Hoax have argued that space travel to the moon is impossible because the Van Allen radiation would kill or incapacitate an astronaut who made the trip. Van Allen himself, still alive and living in Iowa City, has dismissed these ideas.

In practice, Apollo astronauts who travelled to the moon spent very little time in the belts and received a harmless dose. Nevertheless NASA deliberately timed Apollo launches, and used lunar transfer orbits that only skirted the edge of the belt over the equator to minimise the radiation. Astronauts who visited the moon probably have a slightly higher risk of cancer during their lifetimes, but still remain unlikely to become ill because of it.

The Van Allen Belt's And Why They Exist

It is generally understood that the Van Allen belts are a result of the collision of Earth's magnetic field with the solar wind. Radiation from the solar wind then becomes trapped within the magnetosphere. The trapped particles are repelled from regions of stronger magnetic field, where field lines converge. This causes the particle to bounce back and forth between the earth's poles, where the magnetic field increases.

The gap between the inner and outer Van Allen belts is caused by low-frequency radio waves that eject any particles that would otherwise accumulate there. Solar outbursts can pump particles into the gap but they drain again in a matter of days.

The radio waves were originally thought to be generated by turbulence in the radiation belts, but recent work by James Green of the NASA Goddard Space Flight Center comparing maps of lightning activity collected by the Micro Lab 1 spacecraft with data on radio waves in the radiation-belt gap from the IMAGE spacecraft suggests that they're actually generated by lightning within Earth's atmosphere. The radio waves they generate strike the ionosphere at the right angle to pass through it only at high latitudes, where the lower ends of the gap approach the upper atmosphere.

The Soviets once accused the U.S. of creating the inner belt as a result of nuclear testing in Nevada. The U.S. has, likewise, accused the USSR of creating the outer belt through nuclear testing. It is uncertain how particles from such testing could escape the atmosphere and reach the altitudes of the radiation belts. Likewise, it is unclear why, if this is the case, the belts have not weakened since atmospheric testing was banned by treaty. Thomas Gold has argued that the outer belt is left over from the aurora while Dr Alex Dessler has argued that the belt is a result of volcanic activity.

In another view, the belts could be considered a flow of electric current that is fed by the solar wind. With the protons being positive and the electrons being negative, the area between the belts is sometimes subjected to a current flow, which "drains" away. The belts are also thought to drive aurora, lightning and many other electrical effects.

Removing The Belts

The belts are a hazard for artificial satellites and moderately dangerous for human beings and difficult and expensive to shield against.

There is a proposal by the late Robert L. Forward called HiVolt which may be a way to drain at least the inner belt to 1% of its natural level within a year. The proposal involves deploying highly electrically charged tethers in orbit. The idea is that the electrons would be deflected by the large electrostatic fields and intersect the atmosphere and harmlessly dissipate.

Some scientists, however, theorize that the Van Allen belts carry some additional protection against solar wind, which means that a weakening of the belts could harm electronics and organisms, and that they may influence the Earth's telluric current, dissipating the belts could influence the behaviour of Earth's magnetic poles.

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Hall effect

From Wikipedia, the free encyclopedia

The **Hall effect** is the production of a voltage difference (the **Hall voltage**) across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879.[1]

The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current.

Contents

Discovery

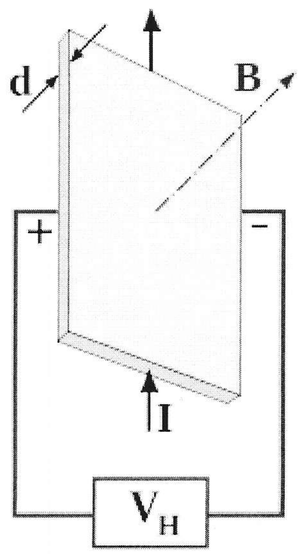
The Hall effect was discovered in 1879 by Edwin Herbert Hall while he was working on his doctoral degree at Johns Hopkins University in Baltimore, Maryland. His measurements of the tiny effect produced in the apparatus he used was an experimental tour de force (http://en.wiktionary.org/wiki/tour_de_force) , accomplished 18 years before the electron was discovered.

Theory

The Hall effect comes about due to the nature of the current in a conductor. Current consists of the movement of many small charge carriers, typically electrons, holes, ions (see Electromigration) or all three. When a magnetic field is present that is not parallel to the direction of motion of moving charges, these charges experience a force, called the Lorentz force.[2] When such a magnetic field is absent, the charges follow approximately straight, 'line of sight' paths between collisions with impurities, phonons, etc. However, when a magnetic field with a perpendicular component is applied, their paths between collisions are curved so that moving charges accumulate on one face of the material. This leaves equal and opposite charges exposed on the other face, where there is a scarcity of mobile charges. The result is an asymmetric distribution of charge density across the Hall element that is perpendicular to both the 'line of sight' path and the applied magnetic field. The separation of charge establishes an electric field that opposes the migration of further charge, so a steady electrical potential is established for as long as the charge is flowing.

It should be noted that in the classical view, there are only electrons moving in the same average direction both in the case of electron or hole conductivity. This cannot explain the opposite sign of the Hall effect observed. The difference is that electrons in the upper bound of the valence band have opposite group velocity and wave vector direction when moving, which can be effectively treated as if positively charged particles (holes) moved in the opposite direction to that of the electrons.

For a simple metal where there is only one type of charge carrier (electrons) the Hall voltage V_H is given by



$$V_H = -\frac{IB}{ned}$$

where I is the current across the plate length, B is the magnetic field, d is the depth (thickness) of the plate, e is the electron charge, and n is the charge carrier density of the carrier electrons.

The Hall coefficient is defined as

$$R_H = \frac{E_y}{j_x B}$$

where j is the current density of the carrier electrons, and E_y is the induced electric field. In SI units, this becomes

$$R_H = \frac{E_y}{j_x B} = \frac{V_H d}{IB} = -\frac{1}{ne}$$

As a result, the Hall effect is very useful as a means to measure either the carrier density or the magnetic field.

One very important feature of the Hall effect is that it differentiates between positive charges moving in one direction and negative charges moving in the opposite. The Hall effect offered the first real proof that electric currents in metals are carried by moving electrons, not by protons. The Hall effect also showed that in some substances (especially p-type semiconductors), it is more appropriate to think of the current as positive "holes" moving rather than negative electrons. A common source of confusion with the Hall Effect is that holes moving to the left are really electrons moving to the right, so one expects the same sign of the Hall coefficient for both electrons and holes. This confusion, however, can only be resolved by modern quantum mechanical theory of transport in solids.[3]

It must be noted though that the sample inhomogeneity might result in spurious sign of the Hall effect, even in ideal van der Pauw configuration of electrodes. For example, positive Hall effect was observed in evidently n-type semiconductors.[4]

Hall effect in semiconductors

When a current-carrying semiconductor is kept in a magnetic field, the charge carriers of the semiconductor experience a force in a direction perpendicular to both the magnetic field and the current. At equilibrium, a voltage appears at the semiconductor edges.

The simple formula for the Hall coefficient given above becomes more complex in semiconductors where the carriers are generally both electrons and holes which may be present in different concentrations and have different mobilities. For moderate magnetic fields the Hall coefficient is[5]

$$R_H = \frac{p\mu_h^2 - n\mu_e^2}{e(p\mu_h + n\mu_e)^2}$$

where n is the electron concentration, p the hole concentration, μ_e the electron mobility, μ_h the hole mobility and e the absolute value of the electronic charge.

For large applied fields the simpler expression analogous to that for a single carrier type holds.

$$R_H = \frac{(p - nb^2)}{e(p + nb)^2}$$

with

$$b = \frac{\mu_e}{\mu_h}$$

Quantum Hall effect

Main article: Quantum Hall effect

For a two dimensional electron system which can be produced in a MOSFET. In the presence of large magnetic field strength and low temperature, one can observe the quantum Hall effect, which is the quantization of the Hall voltage.

Spin Hall effect

Main article: Spin Hall effect

The spin Hall effect consists in the spin accumulation on the lateral boundaries of a current-carrying sample. No magnetic field is needed. It was predicted by M.I. Dyakonov and V.I. Perel in 1971 and observed experimentally more than 30 years later, both in semiconductors and in metals, at cryogenic as well as at room temperatures.

Quantum spin Hall effect

Main article: Quantum Spin Hall Effect

For mercury telluride two dimensional quantum wells with strong spin-orbit coupling, in zero magnetic field, at low temperature, the Quantum spin Hall effect has been recently observed.

Anomalous Hall effect

In ferromagnetic materials (and paramagnetic materials in a magnetic field), the Hall resistivity includes an additional contribution, known as the **anomalous Hall effect** (or the **extraordinary Hall effect**), which depends directly on the magnetization of the material, and is often much larger than the ordinary Hall effect. (Note that this effect is *not* due to the contribution of the magnetization to the total magnetic field.) Although a well-recognized phenomenon, there is still debate about its origins in the various materials. The anomalous Hall effect can be either an *extrinsic* (disorder-related) effect due to spin-dependent scattering of the charge carriers, or an *intrinsic* effect which can be described in terms of the Berry phase effect in the crystal momentum space (k-space).[6]

Hall effect in ionized gases

(See electrochemical instability)

The Hall effect in an ionized gas (plasma) is significantly different from the Hall effect in solids (where the **Hall parameter** is always very inferior to unity). In a plasma, the Hall parameter can take any value. The Hall parameter, β, in a plasma is the ratio between the electron gyrofrequency, Ω_e, and the electron-heavy particle collision frequency, ν:

$$\beta = \frac{\Omega_e}{\nu} = \frac{eB}{m_e \nu}$$

where

- e is the elementary charge (approx. 1.6×10^{-19} C)
- B is the magnetic field (in teslas)
- m_e is the electron mass (approx. 9.1×10^{-31} kg).

The Hall parameter value increases with the magnetic field strength.

Physically, the trajectories of electrons are curved by the Lorentz force. Nevertheless when the Hall parameter is low, their motion between two encounters with heavy particles (neutral or ion) is almost linear. But if the Hall parameter is high, the electron movements are highly curved. The current density vector, J, is no longer colinear with the electric field vector, E. The two vectors J and E make the **Hall angle**, θ, which also gives the Hall parameter:

$$\beta = \tan(\theta)$$

Applications

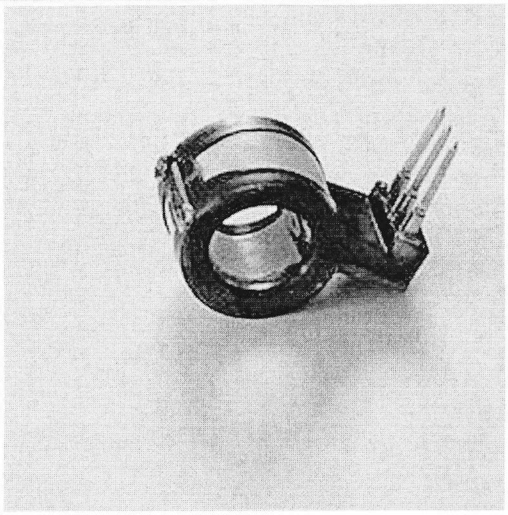
Hall probes are often used as magnetometers, i.e. to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of magnetic flux leakage.

Hall effect devices produce a very low signal level and thus require amplification. While suitable for laboratory instruments, the vacuum tube amplifiers available in the first half of the 20th century were too expensive, power consuming, and unreliable for everyday applications. It was only with the development of the low cost integrated circuit that the Hall effect sensor became suitable for mass application. Many devices now sold as Hall effect sensors in fact contain both the sensor as described above plus a high gain integrated circuit (IC) amplifier in a single package. Recent advances have further added into one package an analog-to-digital converter and I^2C (Inter-integrated circuit communication protocol) IC for direct connection to a microcontroller's I/O port.

Advantages over other methods

Hall effect devices when appropriately packaged are immune to dust, dirt, mud, and water. These characteristics make Hall effect devices better for position sensing than alternative means such as optical and electromechanical sensing.

When electrons flow through a conductor, a magnetic field is produced. Thus, it is possible to create a non-contacting current sensor. The device has three terminals. A sensor voltage is applied across two terminals and the third provides a voltage proportional to the current being sensed. This has several advantages; no additional resistance (a *shunt*, required for the most common current sensing method) need be inserted in the primary circuit. Also, the voltage present on the line to be sensed is not transmitted to the sensor, which enhances the safety of measuring equipment.



Hall effect current sensor with internal integrated circuit amplifier. 8 mm opening. Zero current output voltage is midway between the supply voltages that maintain a 4 to 8 Volt differential. Non-zero current response is proportional to the voltage supplied and is linear to 60 amperes for this particular (25 A) device.

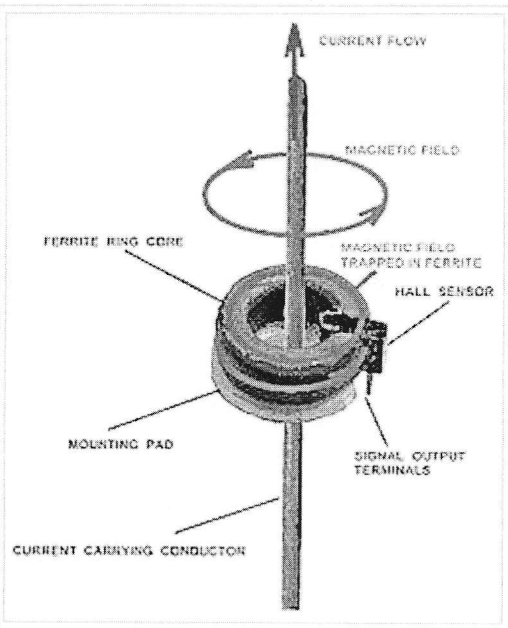
Disadvantages compared with other methods

Magnetic flux from the surroundings (such as other wires) may diminish or enhance the field the Hall probe intends to detect, rendering the results inaccurate. Also, as Hall voltage is often on the order of millivolts, the output from this type of sensor cannot be used to directly drive actuators but instead must be amplified by a transistor-based circuit.

Contemporary applications

Hall effect sensors are readily available from a number of different manufacturers, and may be used in various sensors such as rotating speed sensors (bicycle wheels, gear-teeth, automotive speedometers, electronic ignition systems), fluid flow sensors, current sensors, and pressure sensors. Common applications are often found where a robust and contactless switch or potentiometer is required. These include: electric airsoft guns, triggers of electropneumatic paintball guns, go-cart speed controls, smart phones, and some global positioning systems.

Ferrite toroid Hall effect current transducer

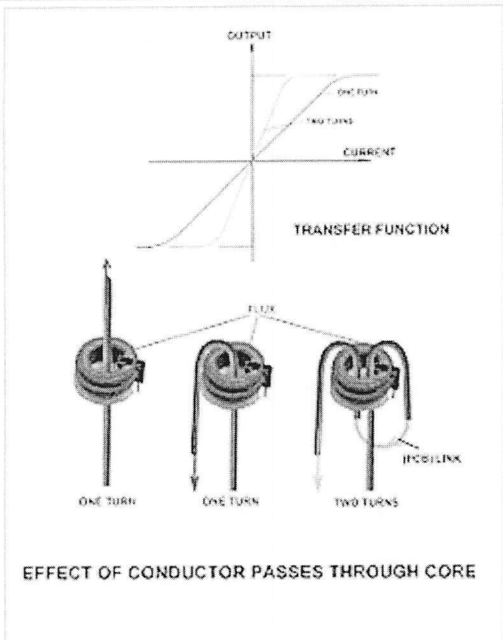


Hall sensors can detect stray magnetic fields easily, including that of Earth, so they work well as electronic compasses: but this also means that such stray fields can hinder accurate measurements of small magnetic fields. To solve this problem, Hall sensors are often integrated with magnetic shielding of some kind. For example, a Hall sensor integrated into a ferrite ring (as shown) can reduce the detection of stray fields by a factor of 100 or better (as the external magnetic fields cancel across the ring, giving no residual magnetic flux). This configuration also provides an improvement in signal-to-noise ratio and drift effects of over 20 times that of a bare Hall device. The range of a given feedthrough sensor may be extended upward and downward by appropriate

Diagram of Hall effect current transducer integrated into ferrite ring.

wiring. To extend the range to lower currents, multiple turns of the current-carrying wire may be made through the opening. To extend the range to higher currents, a current divider may be used. The divider splits the current across two wires of differing widths and the thinner wire, carrying a smaller proportion of the total current, passes through the sensor.

The principle of increasing the number of windings a conductor takes around the ferrite core is well understood, each turn having the effect of multiplying the current under measurement. Often these additional turns are carried out by a staple on the PCB.



Multiple 'turns' and corresponding transfer function.

Split ring clamp-on sensor

A variation on the ring sensor uses a split sensor which is clamped onto the line enabling the device to be used in temporary test equipment. If used in a permanent installation, a split sensor allows the electric current to be tested without dismantling the existing circuit.

Analog multiplication

The output is proportional to both the applied magnetic field and the applied sensor voltage. If the magnetic field is applied by a solenoid, the sensor output is proportional to the product of the current through the solenoid and the sensor voltage. As most applications requiring computation are now performed by small (even tiny) digital computers, the remaining useful application is in power sensing, which combines current sensing with voltage sensing in a single Hall effect device.

Current sensing

By sensing the current provided to a load and using the device's applied voltage as a sensor voltage it is possible to determine the power dissipated by a device.

Position and motion sensing

Hall effect devices used in motion sensing and motion limit switches can offer enhanced reliability in extreme environments. As there are no moving parts involved within the sensor or magnet, typical life expectancy is improved compared to traditional electromechanical switches. Additionally, the sensor and magnet may be encapsulated in an appropriate protective material. This application is used in brushless DC motors.

Automotive ignition and fuel injection

Commonly used in distributors for ignition timing (and in some types of crank and camshaft position sensors for injection pulse timing, speed sensing, etc.) the Hall effect sensor is used as a direct replacement for the mechanical breaker points used in earlier automotive applications. Its use as an ignition timing device in various distributor types is as follows. A stationary permanent magnet and semiconductor Hall effect chip are mounted next to each other separated by an air gap, forming the Hall effect sensor. A metal rotor consisting of windows and tabs is mounted to a shaft and arranged so that during shaft rotation, the windows and tabs pass through the air gap between the permanent magnet and semiconductor Hall chip. This effectively shields and exposes the Hall chip to the permanent magnet's field respective to whether a tab or window is passing though the Hall sensor. For ignition timing purposes, the metal rotor will have a number of equal-sized tabs and windows matching the number of engine cylinders. This produces a uniform square wave output since the on/off (shielding and exposure) time is equal. This signal is used by the engine computer or ECU to control ignition timing. Many automotive Hall effect sensors have a built-in internal NPN transistor with an open collector and grounded emitter, meaning that rather than a voltage being produced at the Hall sensor signal output wire, the transistor is turned on providing a circuit to ground through the signal output wire.

Wheel rotation sensing

The sensing of wheel rotation is especially useful in anti-lock brake systems. The principles of such systems have been extended and refined to offer more than anti-skid functions, now providing extended vehicle handling enhancements.

Electric motor control

Some types of brushless DC electric motors use Hall effect sensors to detect the position of the rotor and feed that information to the motor controller. This allows for more precise motor control

Industrial applications

Applications for Hall Effect sensing have also expanded to industrial applications, which now use Hall Effect joysticks to control hydraulic valves, replacing the traditional mechanical levers with contactless sensing. Such applications include; Mining Trucks, Backhoe Loaders, Cranes, Diggers, Scissor Lifts, etc.

Spacecraft propulsion

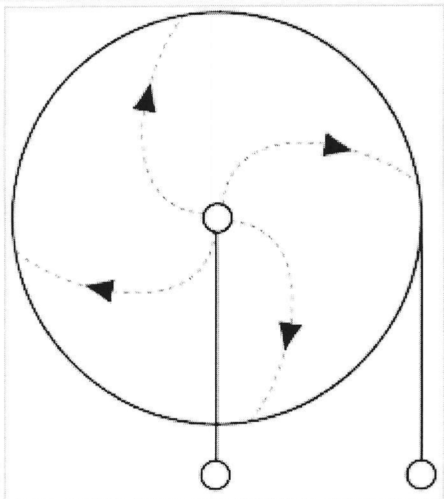
A Hall effect thruster (HET) is a relatively low power device that is used to propel some spacecraft, once they get into orbit or farther out into space. In the HET, atoms are ionized and accelerated by an electric field. A radial magnetic field established by magnets on the thruster is used to trap electrons which then orbit and create an electric field due to the Hall effect. A large potential is established between the end of the thruster where neutral propellant is fed and the part where electrons are produced, so electrons trapped in the magnetic field cannot fall down the potential, and thus are extremely energetic allowing them to ionize neutral atoms. Neutral propellant is pumped into the chamber and is ionized by the trapped electrons. Then positive ions and electrons are ejected from the thruster as a quasineutral plasma, creating thrust.

The Corbino effect

The Corbino effect is a phenomenon involving the Hall effect, but a disc-shaped metal sample is used in place of a rectangular one. Because of its shape the Corbino disc allows the observation of Hall-effect–based magnetoresistance without the associated Hall voltage.

A radial current through a circular disc, subjected to a magnetic field perpendicular to the plane of the disc, produces a "circular" current through the disc.[7]

The absence of the free transverse boundaries renders the interpretation of the Corbino effect simpler than that of the Hall effect.



Corbino disc - dashed curves represent logarithmic spiral paths of deflected electrons

See also

- Capacitor
- Eddy currents
- Elementary charge
- Eric Fawcett
- Hall effect sensor
- Hall effect thruster
- Hall probe
- Nernst effect
- Nernst-Ettinghausen effect
- Quantum Hall effect
- Spin Hall effect
- Thermal Hall effect
- Senftleben-Beenakker effect
- Transducer
- Van der Pauw method
- Coulomb potential between two current loops embedded in a magnetic field
- List of plasma (physics) articles

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Patents

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General

- Interactive Java tutorial on the Hall Effect (http://www.magnet.fsu.edu/education/tutorials/java/halleffect/index.html) National High Magnetic Field Laboratory
- Science World (wolfram.com) (http://scienceworld.wolfram.com/physics/HallEffect.html) article.
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- Spin Hall Effect Detected at Room Temperature (http://physicsweb.org/articles/news/10/9/5/1)
- Hall Effect Sensing and Application (http://content.honeywell.com/sensing/prodinfo/solidstate/technical/hallbook.pdf) . Honeywell documentation on hall effect sensing, interfacing and applications.
- Table with Hall coefficients of different elements at room temparature (http://it.stlawu.edu/~koon/HallTable.html) .

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Categories: Hall effect | Condensed matter physics | Electric and magnetic fields in matter

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Quantum Hall effect

From Wikipedia, the free encyclopedia

The **quantum Hall effect** (or **integer quantum Hall effect**) is a quantum-mechanical version of the Hall effect, observed in two-dimensional electron systems subjected to low temperatures and strong magnetic fields, in which the Hall conductivity σ takes on the quantized values

$$\sigma = \nu \frac{e^2}{h},$$

where e is the elementary charge and h is Planck's constant. The prefactor ν is known as the "filling factor", and can take on either integer (ν = 1, 2, 3, ..) or rational fraction (ν = 1/3, 2/5, 3/7, 2/3, 3/5, 1/5, 2/9, 3/13, 5/2, 12/5 ...) values. The quantum Hall effect is referred to as the integer or fractional quantum Hall effect depending on whether ν is an integer or fraction respectively. The integer quantum Hall effect is very well understood, and can be simply explained in terms of single-particle orbitals of an electron in a magnetic field (see Landau quantization). The fractional quantum Hall effect is more complicated, as its existence relies fundamentally on electron–electron interactions. It is also very well understood as an integer quantum Hall effect, not of electrons but of charge-flux composites known as composite fermions.

Contents

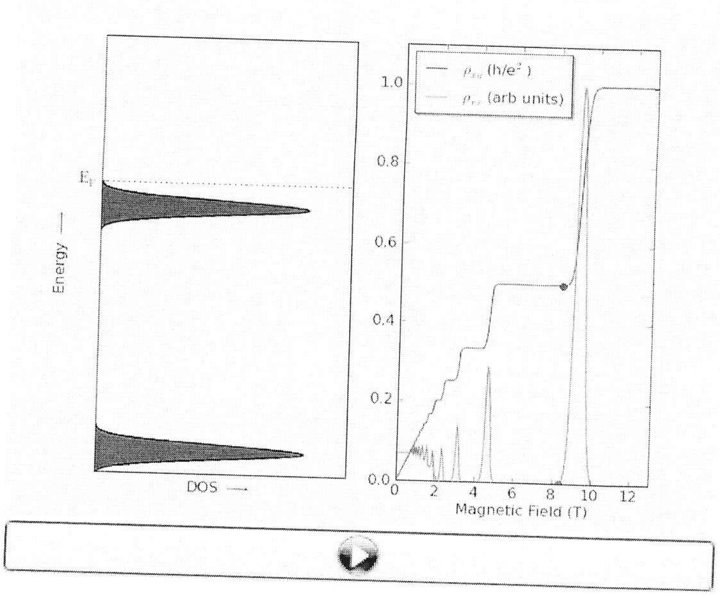
Applications

The quantization of the Hall conductance has the important property of being incredibly precise. Actual measurements of the Hall conductance have been found to be integer or fractional multiples of e^2/h to nearly one part in a billion. This phenomenon, referred to as "exact quantization", has been shown to be a subtle manifestation of the principle of gauge invariance. It has allowed for the definition of a new practical standard for electrical resistance, based on the resistance quantum given by the von Klitzing constant $R_K = h/e^2 =$ 25812.807557(18) Ω.[1] This is named after Klaus von Klitzing, the discoverer of exact quantization. Since 1990, a fixed conventional value $R_{K\text{-}90}$ is used in resistance calibrations worldwide.[2] The quantum Hall effect also provides an extremely precise independent determination of the fine structure constant, a quantity of fundamental importance in quantum electrodynamics.

History

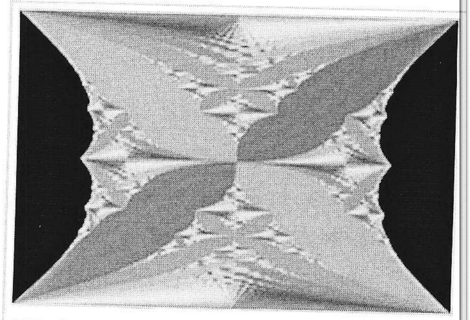
The integer quantization of the Hall conductance was originally predicted by Ando, Matsumoto, and Uemura in 1975, on the basis of an approximate calculation which they themselves did not believe to be true. Several workers subsequently observed the effect in experiments carried out on the inversion layer of MOSFETs. It was only in 1980 that Klaus von Klitzing, working with samples developed by Michael Pepper and Gerhard Dorda, made the unexpected discovery that the Hall conductivity was *exactly* quantized. For this finding, von Klitzing was awarded the 1985 Nobel Prize in Physics. The link between exact quantization and gauge invariance was subsequently found by Robert Laughlin. Most integer quantum Hall experiments are now performed on gallium arsenide heterostructures, although many other semiconductor materials can be used. In 2007, the integer quantum Hall effect was reported in graphene at temperatures as high as room temperature,[3] and in the oxide $ZnO\text{-}Mn_xZn_{1-x}O$.[4]

Integer quantum Hall effect – Landau levels



In two dimensions, when classical electrons are subjected to a magnetic field they follow circular cyclotron orbits. When the system is treated quantum mechanically, these orbits are quantized. The energy levels of these quantized orbitals take on discrete values: $E_n = \hbar\omega_c(n + 1/2)$, where $\omega_c = eB/m$ is the cyclotron frequency. These orbitals are known as Landau levels, and at weak magnetic fields, their existence gives rise to many interesting "quantum oscillations" such as the Shubnikov–de Haas oscillations and the de Haas–van Alphen effect (which is often used to map the Fermi surface of metals). For strong magnetic fields, each Landau level is highly degenerate (i.e. there are many single particle states which have the same energy E_n). Specifically, for a sample of area A, in magnetic field B, the degeneracy of each Landau level is $N = g_s BA/\phi_0$ (where g_s represents a factor of 2 for spin degeneracy, and φ_0 is the magnetic flux quantum). For sufficiently strong B-fields, each Landau level may have so many states that all of the free electrons in the system sit in only a few Landau levels; it is in this regime where one observes the quantum Hall effect.

Mathematics


Hofstadter's butterfly

The integers that appear in the Hall effect are examples of topological quantum numbers. They are known in mathematics as the first Chern numbers and are closely related to Berry's phase. A striking model of much interest in this context is the Azbel-Harper-Hofstadter model whose quantum phase diagram is the Hofstadter's butterfly shown in the figure. The vertical axis is the strength of the magnetic field and the horizontal axis is the chemical potential, which fixes the electron density. The colors represent the integer Hall conductances. Warm colors represent positive integers and cold colors negative integers. The phase diagram is fractal and has structure on all scales. In the figure there is an obvious self-similarity.

Concerning physical mechanisms, impurities and/or particular states (e.g., edge currents) are important for both the 'integer' and 'fractional' effects. In addition, Coulomb interaction is also essential in the fractional quantum Hall effect. The observed strong similarity between integer and fractional quantum Hall effects is explained by the tendency of electrons to form bound states with an even number of magnetic flux quanta, called *composite fermions*.

See also

- Fractional quantum Hall effect
- Composite fermions
- Hall effect
- Hall probe
- Graphene
- Quantum spin Hall effect
- Coulomb potential between two current loops embedded in a magnetic field

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Fractional quantum Hall effect

From Wikipedia, the free encyclopedia

The **fractional quantum Hall effect** (FQHE) is a physical phenomenon in which the Hall conductance of 2D electrons shows precisely quantised plateaus at fractional values of e^2/h. It is a property of a collective state in which electrons bind magnetic flux lines to make new quasiparticles, and excitations have a fractional elementary charge and possibly also fractional statistics. Its discovery and explanation were recognized by the 1998 Nobel Prize in Physics.

Contents

Introduction

The fractional quantum Hall effect (FQHE) is a collective behaviour in a two-dimensional system of electrons. In particular magnetic fields, the electron gas condenses into a remarkable liquid state, which is very delicate, requiring high quality material with a low carrier concentration, and extremely low temperatures. As in the integer quantum Hall effect, a series of plateaus form in the Hall resistance. Each particular value of the magnetic field corresponds to a filling factor (the ratio of electrons to magnetic flux quanta)

$$\nu = p/q,$$

where p and q are integers with no common factors. Here *q* turns out to be an odd number with the exception of two filling factors 5/2 and 7/2. The principal series of such fractions are

$$\frac{1}{3}, \frac{2}{5}, \frac{3}{7}, \text{etc.},$$

and

$$\frac{2}{3}, \frac{3}{5}, \frac{4}{7}, \text{etc.}$$

There were several major steps in the theory of the FQHE.

- **Laughlin states and fractionally-charged quasiparticles**: this theory, proposed by Laughlin, is based on accurate trial wave functions for the ground state at fraction $1/q$ as well as its quasiparticle and quasihole excitations. The excitations have fractional charge of magnitude $e^* = \frac{e}{q}$.

- **Fractional exchange statistics of quasiparticles**: Bertrand Halperin conjectured, and Daniel Arovas, J. R. Schrieffer, and Frank Wilczek demonstrated, that the fractionally charged quasiparticle excitations of the Laughlin states are anyons with fractional statistical angle $\theta = \frac{\pi}{q}$; the wave function acquires phase factor of $e^{i\theta}$ (together with an Aharonov-Bohm phase factor) when identical quasiparticles are exchanged in a counterclockwise sense. A recent experiment seems to give a clear demonstration of this effect [1].

- **Hierarchy states**: this theory was proposed by Duncan Haldane, and further clarified by Halperin, to explain the observed filling fractions not occurring at the Laughlin states' $\nu = 1/q$. Starting with the Laughlin states, new states at different fillings can be formed by condensing quasiparticles into their own Laughlin states. The new states and their fillings are constrained by the fractional statistics of the quasiparticles, producing e.g. $\nu = 2/5$ and $2/7$ states from the Laughlin $\nu = 1/3$ state. Similarly constructing another set of new states by condensing quasiparticles of the first set of new states, and so on, produces a hierarchy of states covering all the odd-denominator filling fractions. This idea has been validated quantitatively,[2] and brings out the observed fractions in a natural order. Laughlin's original plasma model was extended to the hierarchy states by MacDonald and others.[3]

- **Composite fermions**: this theory was proposed by Jain, and further extended by Halperin, Lee and Read. The basic idea of this theory is that as a result of the repulsive interactions, two (or, in general, an even number of) vortices are captured by each electron, forming integer-charged quasiparticles called composite fermions. The fractional states of the electrons are understood as the integer QHE of composite fermions. For example, this makes electrons at filling factors 1/3, 2/5, 3/7, etc. behave in the same way as at filling factor 1, 2, 3, etc. Composite fermions have been observed, and the theory has been partially verified by experiment and computer calculations. Composite fermions are valid even beyond the fractional quantum Hall effect; for example, the filling factor 1/2 corresponds to zero magnetic field for composite fermions, resulting in their Fermi sea. Composite fermion theory provides a complementary description of the Laughlin and hierarchy states. It gives trial wave functions which, though not identical to those produced from the hierarchy picture (the wave functions for the Laughlin states are identical), are in the same universality class, as shown by Read. There are no experimental tests for fractional quantum Hall states that, even in principle, allow one to confirm the composite fermion description while excluding the hierarchy description.

The FQHE was experimentally discovered in 1982 by Daniel Tsui and Horst Störmer, in experiments performed on gallium arsenide heterostructures developed by Arthur Gossard. Tsui, Störmer, and Laughlin were awarded the 1998 Nobel Prize for their work.

Fractionally charged quasiparticles are neither bosons nor fermions and exhibit anyonic statistics. The fractional quantum Hall effect continues to be influential in theories about topological order. Certain fractional quantum Hall phases appear to have the right properties for building a topological quantum computer.

Evidence for fractionally-charged quasiparticles

Experiments have reported results that specifically support the understanding that there are fractionally-charged quasiparticles in an electron gas under FQHE conditions.

In 1995, the fractional charge of Laughlin quasiparticles was measured directly in a quantum antidot electrometer at Stony Brook University, New York.[4] In 1997, two groups of physicists at the Weizmann Institute of Science in Rehovot, Israel, and at the Commissariat à l'énergie atomique laboratory near Paris, detected such quasiparticles carrying an electric current, through measuring quantum shot noise.[5][6] Both of these experiments are somewhat controversial.

A more recent experiment,[7] which measures the quasiparticle charge extremely directly, appears beyond reproach.

Impact of fractional quantum Hall effect

The FQH effect shows the limits of Landau's symmetry breaking theory. Previously it was long believed that the symmetry breaking theory could explain all the important concepts and essential properties of all forms of matter. According to this view the only thing to be done is to apply the symmetry breaking theory to all different kinds of phases and phase transitions. From this perspective, we can understand the importance of the FQHE discovered by Tsui, Stormer, and Gossard.

Different FQH states all have the same symmetry and cannot be described by symmetry breaking theory. Thus FQH states represent new states of matter that contain a completely new kind of order—topological order. The existence of FQH liquids indicates that there is a whole new world beyond the paradigm of symmetry breaking, waiting to be explored. The FQH effect opened up a new chapter in condensed matter physics. The new type of orders represented by FQH states greatly enrich our understanding of quantum phases and quantum phase transitions. The associated fractional charge, fractional statistics, non-Abelian statistics, chiral edge states, etc demonstrate the power and the fascination of emergence in many-body systems.

See also

- Laughlin wavefunction
- Hall probe
- Quantum Hall Effect
- Topological order
- Coulomb potential between two current loops embedded in a magnetic field

Notes

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External links

- University of Cambridge, Semiconductor Physics Group Research (http://www.sp.phy.cam.ac.uk/SPWeb/research/FQHE.html) .
- Fractional quantum Hall effect (List of Authority Articles) (http://xstructure.inr.ac.ru/x-bin/auththeme3.py?level=1&index1=-348131&skip=0)

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Categories: Hall effect | Condensed matter physics | Quantum phases

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Cyclotron

From Wikipedia, the free encyclopedia

A **cyclotron** is a compact type of particle accelerator in which charged particles in a static magnetic field are travelling outwards from the center along a spiral path and get accelerated by radio frequency electromagnetic fields.

A French cyclotron, produced in Zurich, Switzerland in 1937

The cyclotron was invented by Leó Szilárd and first manufactured and patented[1] by Ernest Lawrence, of the University of California, Berkeley who started operating it in 1932.[2] Lawrence read an article about the concept of a drift tube linac by Rolf Widerøe,[3][4] who had also been working along similar lines with the betatron concept. The first European cyclotron was constructed in Leningrad in the physics department of the Radium Institute, headed by Vitali Khlopin. This instrument was first proposed in 1932 by George Gamow and Lev Mysovskii and was installed and running by 1937.[5]

A modern cyclotron for radiation therapy

TRIUMF, Canada's national laboratory for nuclear and particle physics, houses the world's largest cyclotron. The 18m diameter, 4,000 tonne main magnet produces a field of 0.46 T while a 23 MHz 94 kV electric field is used to accelerate the 300 µA beam. TRIUMF is run by a consortium of sixteen Canadian universities and is located at the University of British Columbia, Vancouver, Canada.

Contents

Principle of operation

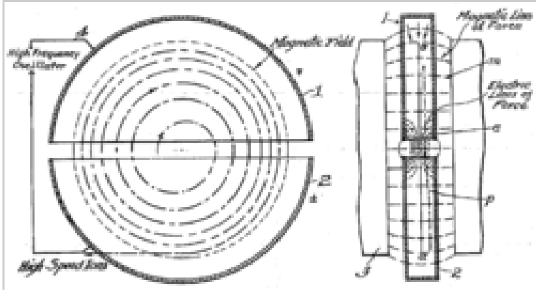


Diagram of cyclotron operation from Lawrence's 1934 patent. The "D" shaped electrodes are enclosed in a flat vacuum chamber, which is installed in a narrow gap between the two poles of a large magnet.

Cyclotrons accelerate charged particle beams using a high frequency alternating voltage which is applied between two "D"-shaped electrodes (also called "dees"). An additional static magnetic field B is applied in perpendicular direction to the electrode plane, enabling particles to re-encounter the accelerating voltage many times at the same phase.[1] To achieve this, the voltage frequency must match the particle's cyclotron resonance frequency

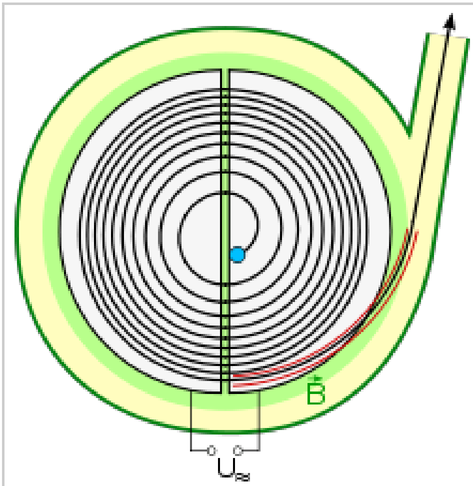
$$f = \frac{qB}{2\pi m},$$

with the relativistic mass *m* and its charge *q*. This frequency is given by equality of centripetal force and magnetic Lorentz force. The particles, injected near the centre of the magnetic field, increase their kinetic energy only when recirculating through the gap between the electrodes; thus they travel outwards along a spiral path.

Beam of electrons moving in a circle. Lighting is caused by excitation of gas atoms in a bulb.

Their radius will increase until the particles hit a target at the perimeter of the vacuum chamber, or leave the cyclotron using a beam tube, enabling their use e.g. for particle therapy. Various materials may be used for a target, and the collisions will create secondary particles which may be guided outside of the cyclotron and into instruments for analysis.

Relativistic considerations



Sketch of a particle being accelerated in a cyclotron, and being ejected trough a beamline.

In *the nonrelativistic approximation*, the frequency does not depend upon the radius of the particle's orbit, since the particle's mass is constant. As the beam spirals out, its frequency does not decrease, and it must continue to accelerate, as it is travelling more distance in the same time.

In contrast to this approximation, as particles approach the speed of light, their relativistic mass increases, requiring either modifications to the frequency, leading to the *synchrocyclotron*, or the magnetic field during the acceleration, leading to the *isochronous cyclotron*. The relativistic cyclotron frequency can be rewritten as

$$f = \frac{qB}{2\pi\gamma m_0} = \frac{f_0}{\gamma},$$

where

$\gamma = 1/\sqrt{1 - \left(\frac{v}{c}\right)^2}$ is the Lorentz factor
m_0 is the particle rest mass
f_0 would be the cyclotron frequency in classical approximation.

The gyroradius for a particle moving in a static magnetic field is then given by

$$r = \frac{\gamma\beta m_0 c}{qB},$$

where $\beta = v/c$ is the relative velocity.

Synchrocyclotron

Main article: Synchrocyclotron

A synchrocyclotron is a cyclotron in which the frequency of the driving RF electric field is varied to compensate for relativistic effects as the particles' velocity begins to approach the speed of light. This is in contrast to the classical cyclotron, where the frequency was held constant, thus leading to the synchrocyclotron operation frequency being

$$f = \frac{f_0}{\gamma} = f_0 \sqrt{1 - \beta^2},$$

where f_0 is the classical cyclotron frequency, and $\beta = v/c$ again is the relative velocity of the particle beam.

The rest mass of an electron is 511 keV/c^2, so the frequency correction is 1% for a magnetic vacuum tube with a 5.11 keV/c^2 direct current accelerating voltage. The proton mass is nearly two thousand times the electron mass, so the 1% correction energy is about 9 MeV, which is sufficient to induce nuclear reactions.

Isochronous cyclotron

An alternative to the synchrocyclotron is the *isochronous cyclotron*, which has a magnetic field that increases with radius, rather than with time. Isochronous cyclotrons are capable of producing much greater beam current than synchrocyclotrons, but require azimuthal variations in the field strength to provide a strong focusing effect and keep the particles captured in their spiral trajectory.

Recalling the relativistic gyroradius

$$r = \frac{\gamma m_0 v}{qB}$$

and the relativistic cyclotron frequency $f = f_0/\gamma$, one can choose B to be proportional to the Lorentz factor, $B = \gamma B_0$. This results in the relation

$$r = \frac{m_0 v}{qB_0}$$

which again only depends on the velocity v, like in the non-relativistic case. Also, the cyclotron frequency is constant in this case.

The transverse de-focusing effect of this radial field gradient is compensated by ridges on the magnet faces which vary the field azimuthally as well. This allows particles to be accelerated continuously, on every period of the radio frequency (RF), rather than in bursts as in most other accelerator types. This principle that alternating field gradients have a net focusing effect is called strong focusing. It was obscurely known theoretically long before it was put into practice.[*citation needed*] Examples of the Isochronous Cyclotron include the Oak Ridge Isochronous Cyclotron (ORIS)which ionises radioactive particles to produce Radioactive Ion Beams and was one of the first AVF cyclotrons produced.[6]

Usage

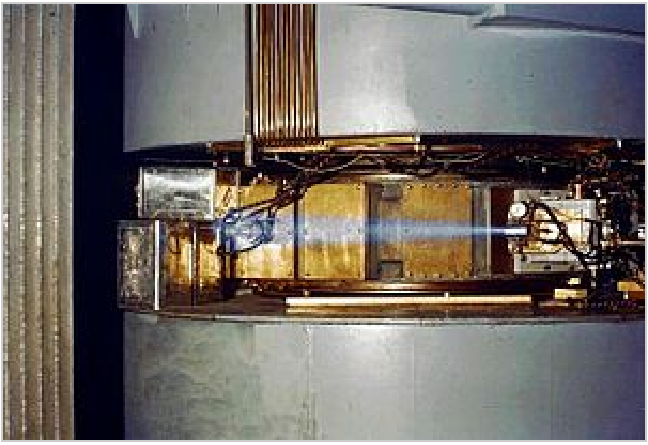
For several decades, cyclotrons were the best source of high-energy beams for nuclear physics experiments; several cyclotrons are still in use for this type of research. The results enable the calculation of various properties, such as the mean spacing between atoms and the creation of various collision products. Subsequent chemical and particle analysis of the target material may give insight into nuclear transmutation of the elements used in the target.

Cyclotrons can be used in particle therapy to treat cancer. Ion beams from cyclotrons can be used, as in proton therapy, to penetrate the body and kill tumors by radiation damage, while minimizing damage to healthy tissue along their path. Cyclotron beams can be used to bombard other atoms to produce short-lived positron-emitting isotopes suitable for PET imaging.

More recently cyclotrons currently installed at hospitals for particle therapy have been retrofitted to enable them to produce technetium-99.[7] Technetium-99 is a diagnostic isotope in short supply due to difficulties at Canada's Chalk River facility.

Advantages and Limitations

The cyclotron was an improvement over the linear accelerators (*linac*s) that were available when it was invented, being more cost- and space-effective due to its iterated interaction with the accelerating field. In the 1920s, it was not possible to generate high power high-frequency radio waves which are used in modern linacs (generated by klystrons), thus requiring unpractically long linac structures for higher-energy particles. The compactness of the device reduces other costs, such as its foundations, radiation shielding, and the enclosing building.



60-inch cyclotron, circa 1939, showing a beam of accelerated ions (likely protons or deuterons) escaping the accelerator and ionizing the surrounding air causing a blue glow

Cyclotrons have a single electrical driver, which saves both money and power, since more expense may be allocated to increasing efficiency. Furthermore, cyclotrons are able to produce a continuous stream of particles at the target, so the average power passed from a particle beam into a target is relatively high.

The magnet portion of a 27" cyclotron. The gray object is the upper pole piece, routing the magnetic field in two loops through a similar part below. The white canisters held conductive coils to generate the magnetic field. The D electrodes are contained in a vacuum chamber that was inserted in the central field gap.

The spiral path of the cyclotron beam can only "sync up" with klystron-type (constant frequency) voltage sources if the accelerated particles are approximately obeying Newton's Laws of Motion. If the particles become fast enough that relativistic effects become important, the beam gets out of phase with the oscillating electric field, and cannot receive any additional acceleration. The classical cyclotron is therefore only capable of accelerating particles up to a few percent of the speed of light. To accommodate increased mass the magnetic field may be modified by appropriately shaping the pole pieces as in the isochronous cyclotrons, operating in a pulsed mode and changing the frequency applied to the dees as in the synchrocyclotrons, either of which is limited by the diminishing cost effectiveness of making larger machines. Cost limitations have been overcome by employing the more complex synchrotron or modern, klystron-driven linear accelerators, both of which have the advantage of scalability, offering more power within an improved cost structure as the machines are made larger.

Related technologies

The spiraling of electrons in a cylindrical vacuum chamber within a transverse magnetic field is also employed in the magnetron, a device for producing high frequency radio waves (microwaves).

The synchrotron moves the particles through a path of constant radius, allowing it to be made as a pipe and so of much larger radius than is practical with the cyclotron and synchrocyclotron. The larger radius allows the use of numerous magnets, each of which imparts angular momentum and so allows particles of higher velocity (mass) to be kept within the bounds of the evacuated pipe. The magnetic field strength of each of the bending magnets is increased as the particles gain energy in order to keep the bending angle constant.

See also

- Beamline
- Cyclotron radiation
- Synchrotron light
- Bremsstrahlung (radiation)
- Electron cyclotron resonance
- Gyroradius
- Gyrotron
- Ion cyclotron resonance
- Linear accelerator
- Particle accelerator
- Storage ring
- Synchrocyclotron
- Synchrotron
- TRIUMF - largest cyclotron in the world
- Radiation reaction

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External links

- Indiana University Cyclotron Facility (http://www.iucf.indiana.edu/) MPRI treats first patient using robotic gantry system.
- "The 88-Inch Cyclotron at LBNL" (http://user88.lbl.gov/)
- "The NSCL at Michigan State University" (http://www.nscl.msu.edu/) Home of coupled K500 and K1200 cyclotrons; the K500, being the first superconducting cyclotron and the K1200 currently the most powerful in the world.
- Rutgers Cyclotron (http://www.physics.rutgers.edu/cyclotron/) and "Building a Cyclotron on a Shoestring" (http://www.physicstoday.org/resource/1/phtoad/v57/i11/p30_s1?bypassSSO=1) Tim Koeth, now a graduate student at Rutgers University, built a 12-inch 1 MeV cyclotron as an undergraduate project, which is now used for a senior-level undergraduate and a graduate lab course.
- "Resonance Spectral Analysis with a Homebuilt Cyclotron" (http://www.niell.org/cyc2.html) an experiment done by Fred M. Niell, III his senior year of high school (1994–95) with which he won the overall grand prize in the ISEF.
- Relativistic accelerator physics PDF (http://casa.colorado.edu/~wcash/APS3730/chapter6.pdf)
- Wired news article (http://www.wired.com/news/politics/0,1283,69726,00.html?tw=wn_tophead_1#) about a neighborhood cyclotron in Anchorage, Alaska
- The Cyclotron Kids (http://thecyclotronkids.org/) A pair of high school students building their own 2.3 MeV cyclotron for experimentation.
- 2010 Small Cyclotron Conference (http://cyclotronconference.org/) Amateur cyclotron builders gathered for the first Small Cyclotron Conference on April 24, 2010.
- TSL - The Svedberg laboratory (http://www.tsl.uu.se/welcome.html) , center for proton therapy and radiation testing, Uppsala, Sweden.
- Oak Ridge Isochronous Cyclotron (http://www.phy.ornl.gov/hribf/accelerator/oricweb/)
- Web site of company IBA (http://www.iba.be)
- Advanced Cyclotron Systems Inc (http://www.advancedcyclotron.com) Commercial manufacturer of high output medical cyclotrons.

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Categories: Accelerator physics

Synchrotron

From Wikipedia, the free encyclopedia

A **synchrotron** is a particular type of cyclic particle accelerator originating from the cyclotron in which the guiding magnetic field (bending the particles into a closed path) is time-dependent, being *synchronized* to a particle beam of increasing kinetic energy. The synchrotron is one of the first accelerator concepts that enable the construction of large-scale facilities, since bending, beam focusing and acceleration can be separated into different components.

The first electron synchrotron was constructed by Edwin McMillan in 1945, although the principle had already been published (unknown to him) in a Russian journal by Vladimir Veksler.[1][2] The first proton synchrotron was designed by Sir Marcus Oliphant[3][4][2] and built in 1952.[2]

Contents

Differentiation

A storage ring is a special type of synchrotron in which the kinetic energy of the particles is kept constant.

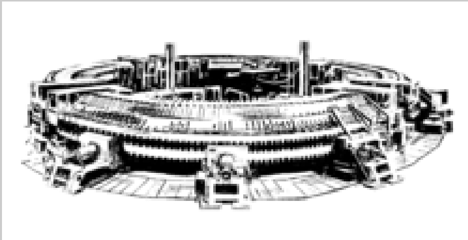
A synchrotron light source is a combination of different accelerator types, including a storage ring with beamlines and usually a synchrotron (which is sometimes called *booster* in this context). Synchrotron light sources in their entirety are sometimes called "synchrotrons", although this is technically incorrect.

A cyclic collider is also a combination of different accelerator types, including two intersecting storage rings and the respective pre-accelerators.

Principle of operation

While a classical cyclotron uses both a constant guiding magnetic field and a constant-frequency electromagnetic field (and is working in classical approximation), its successor, the isochronous cyclotron, works by local variations of the guiding magnetic field, adapting the increasing relativistic mass of particles during acceleration.

In a synchrotron, this adaptation is done by variation of the magnetic field strength in time, rather than in space. For particles that are not ultrarelativistic, the frequency of the applied electromagnetic field may also change to accompany their non-constant circulation time. By increasing these parameters appropriately as the particles gain energy, their circulation path can be held constant as they are accelerated. This allows the vacuum chamber for the particles to be a large thin torus, rather than a disk as in previous, compact accelerator designs. Also, the thin profile of the vacuum chamber allowed for a more efficient use of magnetic fields than in a cyclotron, enabling the cost-effective construction of larger synchrotrons.



A drawing of the Cosmotron

While the first synchrotrons and storage rings like the Cosmotron and ADA strictly used the toroid shape, the strong focusing principle independently discovered by Ernest Courant et al.[5][6] and Nicholas Christofilos[7] allowed the complete separation of the accelerator into components with specialized functions along the particle path, shaping the path into a round-cornered polygon. Some important components are given by radio frequency cavities for direct acceleration, dipole magnets (*bending magnets*) for deflection of particles (to close the path), and quadrupole / sextupole magnets for beam focusing.

The combination of time-dependent guiding magnetic fields and the strong focusing principle enabled the design and operation of modern large-scale accelerator facilities like colliders and synchrotron light sources. The straight sections along the closed path in such facilities are not only required for radio frequency cavities, but also for particle detectors (in colliders) and photon generation devices such as wigglers and undulators (in third generation synchrotron light sources).

The interior of the Australian Synchrotron facility, a synchrotron light source. Dominating the image is the storage ring, showing a beamline at front right. The storage ring's interior includes a synchrotron and a linac.

The maximum energy that a cyclic accelerator can impart is typically limited by the maximum strength of the magnetic fields and the minimum radius (maximum curvature) of the particle path. Thus one method for increasing the energy limit is to use superconducting magnets, these not being limited by magnetic saturation. electron/positron accelerators may also be limited by the emission of synchrotron radiation, resulting in a partial loss of the particle beam's kinetic energy. The limiting beam energy is reached when the energy lost to the lateral acceleration required to maintain the beam path in a circle equals the energy added each cycle.

More powerful accelerators are built by using large radius paths and by using more numerous and more powerful microwave cavities. Lighter particles (such as electrons) lose a larger fraction of their energy when deflected. Practically speaking, the energy of electron/positron accelerators is limited by this radiation loss, while this does not play a significant role in the dynamics of proton or ion accelerators. The energy of such accelerators is limited strictly by the strength of magnets and by the cost.

Injection procedure

Unlike in a cyclotron, synchrotrons are unable to accelerate particles from zero kinetic energy; one of the obvious reasons for this is that its closed particle path would be cut by a device that emits particles. Thus, schemes were developed to inject pre-accelerated particle beams into a synchrotron. The pre-acceleration can be realized by a chain of other accelerator structures like a linac, a microtron or another synchrotron; all of these in turn need to be fed by a particle source comprising a simple high voltage power supply, typically a Cockcroft-Walton generator.

Starting from an appropriate initial value determined by the injection energy, the field strength of the dipole magnets is then increased. If the high energy particle are emitted at the end of the acceleration procedure, e.g. to a target or to another accelerator, the field strength is again decreased to injection level, starting a new *injection cycle*. Depending on the method of magnet control used, the time interval for one cycle can vary substantially between different installations.

Synchrotrons in large-scale facilities


Modern industrial-scale synchrotrons can be very large (here, Soleil near Paris)

One of the early large synchrotrons, now retired, is the Bevatron, constructed in 1950 at the Lawrence Berkeley Laboratory. The name of this proton accelerator comes from its power, in the range of 6.3 GeV (then called BeV for billion electron volts; the name predates the adoption of the SI prefix giga-). A number of transuranium elements, unseen in the natural world, were first created with this machine. This site is also the location of one of the first large bubble chambers used to examine the results of the atomic collisions produced here.

Another early large synchrotron is the Cosmotron built at Brookhaven National Laboratory which reached 3.3 GeV in 1953.[8]

As part of colliders

See also: List of accelerators in particle physics

Until August 2008, the highest energy collider in the world was the Tevatron, at the Fermi National Accelerator Laboratory, in the United States. It accelerates protons and antiprotons to slightly less than 1 TeV of kinetic energy and collides them together. The Large Hadron Collider (LHC), which has been built at the European Laboratory for High Energy Physics (CERN), has roughly seven times this energy (so proton-proton collisions occur at roughly 14 TeV). It is housed in the 27 km tunnel which formerly housed the Large Electron Positron (LEP) collider, so it will maintain the claim as the largest scientific device ever built. The LHC will also accelerate heavy ions (such as lead) up to an energy of 1.15 PeV.

The largest device of this type seriously proposed was the Superconducting Super Collider (SSC), which was to be built in the United States. This design, like others, used superconducting magnets which allow more intense magnetic fields to be created without the limitations of core saturation. While construction was begun, the project was cancelled in 1994, citing excessive budget overruns — this was due to naïve cost estimation and economic management issues rather than any basic engineering flaws. It can also be argued that the end of the Cold War resulted in a change of scientific funding priorities that contributed to its ultimate cancellation. While there is still potential for yet more powerful proton and heavy particle cyclic accelerators, it appears that the next step up in electron beam energy must avoid losses due to synchrotron radiation. This will require a return to the linear accelerator, but with devices significantly longer than those currently in use. There is at present a major effort to design and build the International Linear Collider (ILC), which will consist of two opposing linear accelerators, one for electrons and one for positrons. These will collide at a total center of mass energy of 0.5 TeV.

As part of synchrotron light sources

See also: List of synchrotron radiation facilities

Synchrotron radiation also has a wide range of applications (see synchrotron light) and many 2nd and 3rd generation synchrotrons have been built especially to harness it. The largest of those 3rd generation synchrotron light sources are the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, the Advanced Photon Source (APS) near Chicago, USA, and SPring-8 in Japan, accelerating electrons up to 6, 7 and 8 GeV, respectively.

Synchrotrons which are useful for cutting edge research are large machines, costing tens or hundreds of millions of dollars to construct, and each beamline (there may be 20 to 50 at a large synchrotron) costs another two or three million dollars on average. These installations are mostly built by the science funding agencies of governments of developed countries, or by collaborations between several countries in a region, and operated as infrastructure facilities available to scientists from universities and research organisations throughout the country, region, or world. More compact models, however, have been developed, such as the Compact Light Source.

Applications

- Life sciences: protein and large molecule crystallography
- LIGA based microfabrication
- Drug discovery and research
- "Burning" computer chip designs into metal wafers
- Analysing chemicals to determine their composition
- Observing the reaction of living cells to drugs
- Inorganic material crystallography and microanalysis
- Fluorescence studies
- Semiconductor material analysis and structural studies
- Geological material analysis
- Medical imaging
- Proton therapy to treat some forms of cancer

See also

- List of synchrotron radiation facilities
- Synchrotron X-ray tomographic microscopy
- Energy amplifier
- Superconducting Radio Frequency

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8. ^ The Cosmotron (http://www.bnl.gov/bnlweb/history/cosmotron.asp)

External links

- Canadian Light Source (http://www.lightsource.ca)
- Australian Synchrotron (http://www.synchrotron.org.au)
- French synchrotron Soleil (http://www.synchrotron-soleil.fr/)
- Diamond UK Synchrotron (http://www.diamond.ac.uk)
- Lightsources.org (http://www.lightsources.org/cms/)
- CERN Large Hadron Collider (http://lhc-new-homepage.web.cern.ch/lhc-new-homepage)
- Synchrotron Light Sources of the World (http://www-als.lbl.gov/als/synchrotron_sources.html)
- A Miniature Synchrotron: (http://www.technologyreview.com/Biotech/20149/) room-size synchrotron offers scientists a new way to perform high-quality x-ray experiments in their own labs, *Technology Review*, February 4, 2008
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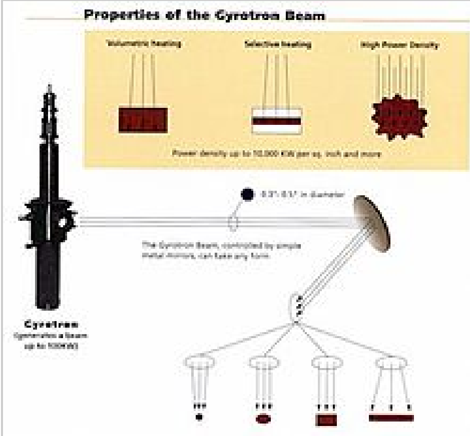
Categories: Accelerator physics

Gyrotron

From Wikipedia, the free encyclopedia

Gyrotrons are high powered vacuum tubes which emit millimeter-wave beams by bunching electrons with cyclotron motion in a strong magnetic field. Output frequencies range from about 20 to 250 GHz, covering wavelengths from microwave to the edge of the terahertz gap. Typical output powers range from tens of kilowatts to 1-2 megawatts. Gyrotrons can be designed for pulsed or continuous operation.



Properties of the Gyrotron beam

Contents

Principle of operation

The gyrotron is a type of free electron maser (microwave amplification by stimulated emission of radiation). It has high power at millimeter wavelengths because its dimensions can be much larger than the wavelength, unlike conventional vacuum tubes, and it is not dependent on material properties, as are conventional masers. The bunching depends on a relativistic effect called the Cyclotron Resonance Maser instability. The electron speed in a gyrotron is slightly relativistic (comparable to but not close to the speed of light). This contrasts to the free electron laser (and xaser) that work on different principles and which electrons are highly relativistic.

Applications

Gyrotrons are used for many industrial and high technology heating applications. For example, gyrotrons are used in nuclear fusion research experiments to heat plasmas, and also in manufacturing industry as a rapid heating tool in processing glass, composites, and ceramics, as well as for annealing (solar and semiconductors). Military applications include the Active Denial System.

Manufacturers

The gyrotron was invented in the Soviet Union.[1] Present makers include Communications & Power Industries (USA), Gycom (Russia), Thales Group (EU), Toshiba (Japan) and Bridge12 Technologies, Inc. (http://www.bridge12.com) . System developers include Gyrotron Technology, Inc (http://gyrotrontech.com)

See also

- Electron cyclotron resonance
- Magnetron
- Klystron
- Cyclotron
- Fusion power
  - Tokamak
- Terahertz radiation

References

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External links

- Gyrotron (http://phys-el.rphf.spbstu.ru/LOUKSHA/gyrotron.htm)
- The Gyrotron: A High Frequency Microwave Amplifier (http://ipnpr.jpl.nasa.gov/progress_report2/42-52/52C.PDF) by A. Kupiszezwki.

Categories: Microwave technology | Optical devices | Terahertz technology | Soviet inventions | Vacuum tubes | Particle accelerators

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