[Click Here for Sample Questions] A betatron is a type of particle accelerator that uses the electric field produced by a fluctuating magnetic field to accelerate electrons, or beta particles, to high speeds in a circular orbit. The betatron is made out of an evacuated tube that has been bent into a circle and is encased in an electromagnet with windings that are parallel to the loop. These windings provide a variable magnetic field that periodically reverses direction due to an alternating electric current. The magnetic field's direction, intensity, and rate of change inside the orbit all have values that are suitable for pushing electrons in one direction during the first quarter of the alternating current cycle. Two forcesone operating in the direction of the electrons' travel and the other at a right angle to that directionare responsible for controlling their acceleration. The electric field generated by induction from the heightened magnetic field within the circle accelerates the electrons by exerting a force in the direction of their travel. The second force called the perpendicular force, emerges as the electrons pass through the magnetic field and keep them in a closed-loop orbit. Betatron Read More: Synchrotron Operation Principle of Betatron [Click Here for Previous Year Questions] Similar to how current is induced in a transformer's secondary coil, this kind of accelerator uses Faraday's law to move electrons in a circle around a torus. This occurs as electrons in the vacuum torus are accelerated by the betatron's primary coil's fluctuating magnetic field. For the stable electron orbit in such an accelerator, it obeys an equation 0 = 2r02H0 Here, 0 is the flux of the enclosed area of the electron orbit, r0 is the electron orbits radius, and H0 is the magnetic field at r0. So the value of H0 from the equation will be, H0= 1/2 (0/r02) From this value of H0 it can be concluded that the average magnetic field throughout the orbit's circular cross-section should be cut in half. Read More: Cyclotron Betatron Oscillation [Click Here for Sample Questions] In all circular accelerators, betatron oscillation refers to the oscillations of particles about their stable orbits. These are the steady oscillations in the horizontal and vertical planes around the equilibrium orbit. By Hills equation, the transverse motion of such an accelerator is determined as d2x/ds2 + K(s)x = 0 Read More: Hadron Applications of Betatron [Click Here for Previous Year Questions] A few applications of betatron are The Betatron is utilized as an X-ray and gamma-ray generator when an electron beam must impact a metal plate. About 300 MeV of very energized electron beams are produced by the betatron. High-energy electrons are required to research the applications of particle physics. X-rays produced by Betatron are widely used in both industrial and medicinal settings. It could be a way to find out about the solar flare. Read More: Quark Limitations of Betatron [Click Here for Sample Questions] The following lists outline the betatron's drawbacks: The particle's maximum energy has an impact on the magnetic field's strength. The magnet's physical size and iron saturation are the causes of the magnetic field's decline. The secondary coil of the transformer is a betatron. The electrons are only capable of acceleration in a vacuum. The acceleration procedure can only be carried out in a circular vacuum tube. The betatron can function when there is a varying magnetic field and a constant electric field. Read More: Angular Motion Things to Remember A specific kind of particle oscillator called a betatron is utilized to increase electron energy up to 300 MeV. A betatron is a type of particle accelerator that uses the electric field produced by a fluctuating magnetic field to accelerate electrons, or beta particles, to high speeds in a circular orbit. For the stable electron orbit in such an accelerator, it obeys an equation 0 = 2r02H0 Here, 0 is the flux of the enclosed area of the electron orbit, r0 is the electron orbits radius, and H0 is the magnetic field at r0. The average magnetic field throughout the orbit's circular cross-section should be cut in half. When an electron beam has to strike a metal plate, the Betatron is used as an X-ray and gamma-ray generator. The betatron can function when there is a varying magnetic field and a constant electric field. Previous Year Questions Electric flux at a point in an electric field is.. The correct order of acid strength of the following carboxylic acids is..[Jee Advanced 2019] The measurement of voltmeter in the following circuit is...[AIIMS 2017] Angular velocity of minute hand of a clock is...[MP PMT 2004] Highly pure dilute solution of sodium in liquid ammonia...[Jee Advanced 1998] A gas mixture consists of22moles of oxygen and44moles of Argon at temperature T. Neglecting all vibrational modes, the total internal energy of the system is..[NEET UG 2017] Alkali halides do not show Frenkel defect because.. Let R = {(1,3),(4,2),(2,4),(2,3),(3,1)}be a relation on the set A = {1,2,3,4}. The relation R is...[AIEEE 2004] Degree of freedom for polyatomic gas...[AIIMS 2012] In pyrrole, the electron density is maximum on...[NEET UG 2016] Ques. What are the applications of Betatron? (3 Marks) Ans. A few applications of betatron are The Betatron is utilized as an X-ray and gamma-ray generator when an electron beam must impact a metal plate. About 300 MeV of very energized electron beams are produced by the betatron. High-energy electrons are required to research the applications of particle physics. X-rays produced by Betatron are widely used in both industrial and medicinal settings. It could be a way to find out about the solar flare. Ques. Betatron is an example of which type of accelerator? (1 Mark) Ans. An example of an electromagnetic or electrodynamic particle accelerator is the betatron. Ques. What are the types of electrodynamics or electromagnetic particle accelerator? (1 Mark) Ans. There are two types of electromagnetic particle accelerators 1. Linear accelerator and 2. Circular accelerator. Ques. What is the basic principle of betatron? (3 Marks) Ans. This type of accelerator employs Faraday's law to drive electrons in a circle around a torus, much as how current is generated in a transformer's secondary coil. This happens because of the magnetic field fluctuations in the betatron's primary coil, which accelerate electrons in the vacuum torus. In such an accelerator, the stable electron orbit follows an equation 0 = 2r02H0 Here, 0 is the flux of the enclosed area of the electron orbit, r0 is the electron orbits radius, and H0 is the magnetic field at r0. So the value of H0 from the equation will be, H0 = 1/2 (0/r02) From this value of H0 it can be concluded that the average magnetic field throughout the orbit's circular cross-section should be cut in half. Ques. What is the difference between a cyclotron and a betatron? (3 Marks) Ans. Cyclotron Betatron Up to 80 MeV energies are used to accelerate positive ions. Up to 300 MeV of electron energy is accelerated. As long as the resonance state is sustained, ions are accelerated. As long as the betatron state is sustained, electrons are accelerated. Ions are accelerated at the peak of each half-cycle. Electrons are accelerated only during the 1st quarter of each cycle. In a circular orbit with a growing radius, ions are accelerated. In an orbit with a set radial distance, electrons are accelerated. It uses a uniform magnetic field. It uses expanding magnetic field. Accelerated ions are used to study nuclear reactions. Accelerated electrons are used to produce hard X-rays. Ques. What are the types of particle accelerators? (2 Marks) Ans. The two types of particle accelerators are 1. Electrostatic particle accelerator and 2. Electrodynamics particle accelerator. Ques. What is a particle accelerator? (1 Mark) Ans. It is a device that propels high-speed, high-energy charged particles in well-defined beams using electromagnetic fields. Ques. State two limitations of using a betatron. (2 Marks) Ans. The following lists outline the betatron's drawbacks: The strength of the magnetic field is influenced by the particle's maximal energy. The magnet's physical size and iron saturation are the causes of the magnetic field's decline. For Latest Updates on Upcoming Board Exams, Click Here: Check-Out: Share copy and redistribute the material in any medium or format for any purpose, even commercially. Adapt remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the license terms. Attribution You must give appropriate credit , provide a link to the license, and indicate if changes were made . You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. ShareAlike If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. No additional restrictions You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits. You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation . No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. Cyclic particle acceleratorOne of the first betatrons built by Donald Kerst (visible right) at University of Illinois, 1940. Its 4-ton magnet could accelerate electrons to 24MeV.A German 6MeV betatron (1942)A 35MeV betatron used for photonuclear physics at the University of Melbourne.A betatron is a type of cyclic particle accelerator for electrons. It consists of a torus-shaped vacuum chamber with an electron source. Circling the torus is an iron transformer core with a wire winding around it. The device functions similarly to a transformer, with the electrons in the torus-shaped vacuum chamber as its secondary coil. An alternating current in the primary coils accelerates electrons in the vacuum around a circular path. The betatron was the first machine capable of producing electron beams at energies higher than could be achieved with a simple electron gun, and the first circular accelerator in which particles orbited at a constant radius.[1]The concept of the betatron had been proposed as early as 1922 by Joseph Slepian.[2] Through the 1920s and 30s a number of theoretical problems related to the device were considered by scientists including Rolf Wideroe,[3][4] Ernest Walton, and Max Steenbeck.[5] The first working betatron was constructed by Donald Kerst at the University of Illinois Urbana-Champaign in 1940.[6][7][8]After the discovery in the 1800s of Faraday's law of induction, which showed that an electromotive force could be generated by a changing magnetic field, several scientists speculated that this effect could be used to accelerate charged particles to high energies.[2] Joseph Slepian proposed a device in 1922 that would use permanent magnets to steer the beam while it was accelerated by a changing magnetic field.[9] However, he did not pursue the idea past the theoretical stage.In the late 1920s, Gregory Breit and Merle Tuve at the Bureau of Terrestrial Magnetism constructed a working device that used varying magnetic fields to accelerate electrons. Their device placed two solenoidal magnets next to one another and fired electrons from a gun at the outer edge of the magnetic field. As the field was increased, the electrons accelerated in to strike a target at the center of the field, producing X-rays. This device took a step towards the betatron concept by shaping the magnetic field to keep the particles focused in the plane of acceleration.[2]In 1929, Rolf Wideroe made the next major contribution to the development of the theory by deriving the Wideroe Condition for stable orbits. He determined that in order for the orbit radius to remain constant, the field at the radius must be exactly half of the average field over the area of the magnet. This critical calculation allowed for the development of accelerators in which the particles orbited at a constant radius, rather than spiraling inward, as in the case of Breit and Tuve's machine, or outward, as in the case of the cyclotron.[10] Although Wideroe made valuable contributions to the development of the theory of the Betatron, he was unable to build a device in which the electrons orbited more than one and a half times, as his device had no mechanism to keep the beam focused.[2]Simultaneously with Wideroe's experiments, Ernest Walton analyzed the orbits of electrons in a magnetic field, and determined that it was possible to construct an orbit that was radially focused in the plane of the orbit. Particles in such an orbit which moved a small distance away from the orbital radius would experience a force pushing them back to the correct radius.[2] These oscillations about a stable orbit in a circular accelerator are now referred to as betatron oscillations.[10]In 1935 Max Steenbeck applied in Germany for a patent on a device that would combine the radial focusing condition of Walton with the vertical focusing used in Breit and Tuve's machine.[5] He later claimed to have built a working machine, but this claim was disputed.[2]The first team unequivocally acknowledged to have built a working betatron was led by Donald Kerst at the University of Illinois. The accelerator was completed on July 15, 1940.[7]In a betatron, the changing magnetic field from the primary coil accelerates electrons injected into the vacuum torus, causing them to circle around the torus in the same manner as current is induced in the secondary coil of a transformer (Faraday's law).The stable orbit for the electrons satisfies 0 = 2 r 0 2 H 0 , {\displaystyle \theta _{0}=2\pi r_{0}^{2}H_{0},} where 0 {\displaystyle \theta _{0}} is the flux within the area enclosed by the electron orbit, r 0 {\displaystyle r_{0}} is the radius of the electron orbit, and H 0 {\displaystyle H_{0}} is the magnetic field at r 0 {\displaystyle r_{0}} .In other words, the magnetic field at the orbit must be half the average magnetic field over its circular cross section: H 0 = 1 2 0 r 0 2 . {\displaystyle \Leftrightarrow H_{0}={\frac {1}{2}}{\frac {\theta _{0}}{\pi r_{0}^{2}}}.} This condition is often called Widere's condition.[11]The name "betatron" (a reference to the beta particle, a fast electron) was chosen during a departmental contest. Other proposals were "rheotron", "induction accelerator", "induction electron accelerator",[12] and even "Auerordentlichehochgeschwindigkeitselektronenentwickelndesschwerarbeitsbeigollitron", a suggestion by a German associate, for "Hard working by golly machine for generating extraordinarily high velocity electrons"[13][14] or perhaps "Extraordinarily high velocity electron generator, high energy by golly-tron."[15]Betatrons were historically employed in particle physics experiments to provide high-energy beams of electronsup to about 300 MeV. If the electron beam is directed at a metal plate, the betatron can be used as a source of energetic x-rays, which may be used in industrial and medical applications (historically in radiation oncology). A small version of a betatron was also used to provide a source of hard X-rays (by deceleration of the electron beam in a target) for prompt initiation of some experimental nuclear weapons by means of photon-induced fission and photofission in the bomb core.[16][17][18]The Radiation Center, the first private medical center to treat cancer patients with a betatron, was opened by Dr.O.Arthur Stiennon in a suburb of Madison, Wisconsin in the late 1950s.[19]The maximum energy that a betatron can impart is limited by the strength of the magnetic field due to the saturation of iron and by practical size of the magnet core. The next generation of accelerators, the synchrotrons, overcame these limitations.^ "Betatron | particle accelerator". Encyclopedia Britannica. Retrieved 2019-01-24.^ a b c d e f Kerst, Donald W. (January 1946). "Historical Development of the Betatron". Nature. 157 (3978): 9095. Bibcode:1946Natur.157...90K. doi:10.1038/157090a0. PMID21015096. S2CID42153256.^ Widere, R. 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March 20, 1950. p.131.^ Big Science: The Growth of Large-Scale Research, ISBN978-0-8047-1879-0.^ Nuclear Weapons Archive, Tumbler shot series, item George.^ Nuclear Weapons Archive, Elements of Fission Weapon Design, section 4.1.8.2.^ Wisconsin alumnus, Volume 58, Number 15 (July 25, 1957).Wikimedia Commons has media related to Betatrons.The Betatron at UIUCRetrieved from " Betatron is a particle accelerator that is used to accelerate beta particles, usually electrons. It works on the principle of electromagnetic induction to accelerate charged particles to high energy particles. They were one of the earliest particle accelerator developed for research and development in the area of particle physics. In this article, we will learn in detail about betatron, its construction, working principle, advantages, disadvantages, uses and limitations. We will also compare betatron with cyclotron in this article. What is a Betatron? Betatron is a circular induction accelerator used for electron acceleration. A betatron, utilized in high-energy physics, propels electrons to relativistic velocities. In other words, we can describe a betatron as a type of particle accelerator that produces high-energy electrons, or positrons. It operates on the principle of electromagnetic induction. It consists of a large toroidal vacuum chamber surrounded by an electromagnet. Alternating current (AC) is passed through the electromagnet, generating a time-varying magnetic field. Consequently, this field induces a voltage in a metal tube within the chamber, accelerating electrons to high energies as they spiral around the chamber due to the Lorentz force. Properties of BetatronThe properties of betatron are mentioned below: Energy of a BetatronThe maximum electron kinetic energy achieved by betatrons is about 300 MeV. The energy limit is determined in part by the practical size of pulsed magnets and in part by synchrotron radiation. Betatron FrequencyThe betatron frequency or v value is the frequency of the betatron motion of the circulating beam per one revolution in the ring. One important parameter of particle dynamics in an accelerator is the betatron frequency and its dependence on a particles amplitude. The first mention of the betatron frequency was in the 1941 pioneering work by Kerst and Serber. They defined it as the fractional number of particle oscillations around the orbit per one revolution period in a betatron. Conditions for BetatronA betatron acts as a secondary coil of the transformer. It helps to accelerate the electrons only in a vacuum. This process of acceleration can only be conducted within a circular vacuum tube. Betatron is functional under the conditions of the variable magnetic field and constant electric field. Oscillation in BetatronThe particles undergo oscillatory motion within the Betatron. Electrons move back and forth along their circular path as they gain energy. The oscillations are driven by the alternating magnetic field, which continuously accelerates the particles. The oscillation of the particle is in stable orbits. The motion of the particle is described by Hill's equation which is given as d2x/dt2 + 2(t)x=0 Where x(t) is the unknown function of time.t is the independent variable (time).(t) is a function of time, representing the frequency or angular frequency of the oscillations.Types of BetatronsThere are mainly two types of betatrons: Classic BetatronResonant BetatronClassic BetatronClassic betatron is also known as a vacuum betatron. It operates by inducing an alternating magnetic field within a vacuum chamber using a large doughnut-shaped magnet and a high-frequency alternating current (AC). As the magnetic field changes, it induces a circular motion in the electrons, causing them to accelerate. The classic betatron was the original design proposed by Donald Kerst and was first demonstrated in 1940. Resonant BetatronResonant betatron is also known as a magnetic induction accelerator. It uses a series of induction coils or magnets arranged along the path of the particle beam. The magnets produce a changing magnetic field, which induces a resonant oscillation in the particles. The resonant betatron can operate at higher energies and with higher efficiency compared to the classic betatron. Apart from the above types of betatron, they are also classified on the basis of the shape of the vacuum chamber. Based on this, the betatrons are classified as follows: Circular BetatronRacetrack BetatronCircular BetatronThe traditional Betatron design consists of a circular vacuum chamber with a toroidal shape.Electrons are accelerated along a circular path inside the chamber by the changing magnetic field generated by the surrounding electromagnet.Circular Betatrons are commonly used in research laboratories and medical facilities for various applications, including medical imaging and radiation therapy.Racetrack BetatronRacetrack Betatron has a straight section connected to semi-circular ends, resembling a racetrack or oval shape.Electrons are accelerated along the straight section before entering the semi-circular ends where they complete their circular path.Racetrack Betatrons are less common than circular Betatrons but may offer certain advantages in specific applications or research settings.The above types of Betatrons operate on the same principle of electromagnetic induction to accelerate electrons, but they may differ in their design and application. The choice between circular and racetrack Betatrons depends on factors such as the desired energy output, space constraints, and other factors. Principle of BetatronBetatron particle accelerator operates on the following principle: When an electric current is passed through the magnet, it generates a strong magnetic field inside the chamber. To accelerate the electrons, a series of alternating current (AC) pulses are sent through a coil located inside the chamber. These pulses create a rapidly changing magnetic field, which in turn induces an electric field. The electric field accelerates the electrons in a circular path within the chamber. As the electrons gain energy, their velocity increases, and they move in larger orbits. This process continues until the electrons reach their maximum speed or desired energy level. Betatron Construction and WorkingThe construction and working of Betatron is discussed below: Construction of BetatronA betatron consist of following parts: Vacuum Chamber: Betatron has a vacuum chamber also called Doughnut Chamber to contain the path of the accelerated particles. It is positioned between two electromagnet poles and are driven by an alternating current(AC), with a frequency of 80Hz to 180 Hz. Vacuum chamber also minimizes collisions between the accelerated particles and air molecules, ensuring efficient acceleration.Primary Coil: A large coil of wire, known as the primary coil, is wound around the vacuum chamber. The primary coil is connected to an alternating current (AC) power supply. This AC power supply generates the changing magnetic field necessary for particle acceleration through electromagnetic induction.Injection System: Charged particles, such as electrons, are injected into the vacuum chamber at a specific injection point. The injection system include electron guns or other similar devices to introduce the particles into the accelerating region of the betatron.Detector Systems: Betatrons also have detector systems to monitor and measure the accelerated particles' properties, such as energy, trajectory, and intensity.Power Supply: A power supply is required to provide electrical power to the primary coil for generating the alternating magnetic field. The power supply must be enough to achieve the desired magnetic field strength and frequency.Cooling System: Betatrons also have cooling system. This is because the primary coil and other components of the betatron may generate heat during operation. Hence, to maintain optimal performance it require cooling system. Working of BetatronThe working of Betatron is discussed in detail below: Generation of Alternating Magnetic Field: A large coil of wire is connected to an alternating current (AC) power supply. When the AC power supply is turned on, it generates a alternating magnetic field within the vacuum chamber of the betatron. This changing magnetic field induces an electric field within the vacuum chamber due to electromagnetic induction.Injection of Charged Particles: Charged particles, such as electrons, are injected into the vacuum chamber at a specific injection point. Acceleration of Particles: As the charged particles travel along the circular path within the vacuum chamber, they experience an electric field induced by the changing magnetic field. This electric field exerts a force on the particles, accelerating them as they move around the circular path.Energy Gain: With each pass through the accelerating region of the betatron, the particles gain energy due to the induced electric field. The energy gained by the particles is proportional to the strength and frequency of the magnetic field, as well as the number of revolutions they make around the circular path.Detection and Analysis: After being accelerated, the particles can be directed towards various experimental apparatus or detectors for analysis.When the electromagnets are powered and an electron occurs at K (the doughnut tubes cathode), the magnetic field grows. This growing magnetic field has two effects, which are: By altering the magnetic flux, which provides the electron with additional energy, induced e.m.f. is created in the electron orbit. Faradays law says that e.m.f = (d)/(dt)The operation of a magnetic field whose direction is perpendicular to the electron velocity causes a radial force (magnetic force) that maintains the electrons circular motion. Centripetal force balances the force. This is given as qvB = (mv2)/rThe electron is only held in the tube for T/4 seconds because the particle acceleration only happens during the period when the flux grows from zero to its greatest value. After this, the flux starts to decrease, which causes the electrons velocity to decrease. The growing field provides the greater magnetic field that the quicker electrons require to maintain their constant radius of motion. Difference between Betatron and CyclotronBetatron and Cyclotron are two commonly used particle accelerators. The difference between betatron and cyclotron is tabulated below: Betatron Cyclotron It is a particular type of particle accelerator modified primarily to accelerate beta particles or electrons. A cyclotron is a type of particle accelerator that uses a spiral path to accelerate charged particles. Upto 300 MeV of electron energy is accelerated. Upto 80 MeV energies are used to accelerate positive ions. It has expanding magnetic field. It has constant magnetic field. Electrons are accelerated as long as the betatron state is sustained. Ions are accelerated as long as the resonance state is sustained. Only the first part of each cycle experiences electron acceleration. At the apex of each half cycle, ions accelerate. Betatron uses a circular path for accelerating charged particles. Cyclotron uses a spiral path for accelerating charged particles. Betatron is modern compared to cyclotron. Cyclotron is the earliest form of the accelerator Its path is circular Its path is semicircular or spiral Advantages and Disadvantages of BetatronThe advantages and disadvantages of betatron are discussed below: Advantages of BetatronThe advantages of betatron are: Betatron has the advantage that it produce full voltage on a secondary coil and then apply that voltage to a high-vacuum x-ray tube. Betatrons can achieve high energy gains for charged particles in a relatively short distance, making them efficient for certain particle acceleration tasks.They typically have simpler designs compared to other types of accelerators, leading to easier maintenance and lower downtime for repairs.Betatrons can operate continuously once they are started, which is advantageous for applications requiring a steady beam of particles.They are relatively compact compared to other types of particle accelerators like cyclotrons or linear accelerators. This makes them suitable for applications where space is limited.Disadvantages of BetatronThe disadvantages of betatron are: Only a circular vacuum tube is capable of conducting the acceleration process.Only in a vacuum can the electrons be accelerated.The procedure by which electrons are ejected is complex.When there is a fluctuating magnetic field and a steady electric field, the betatron can operate.Power requirements are huge.Uses of BetatronBetatrons are used for following applications: The high energy electrons can be used in the field of particle physicsBetatron provides high energy beam electrons of about 300 MeV.It is used as a source of X-rays and gamma rays if the electron beam is directed onto a metal plate. It has industrial applications and is used in the medical field.It is used for Radiography.They are used in medical applications, particularly in radiation therapy for cancer treatment. They can generate high-energy electron beams that can be focused on tumors with precision, minimizing damage to surrounding healthy tissue.Limitation of BetatronAlthough, Betatrons offer many advantages in terms of compactness and simplicity compared to other particle accelerators, they also have limitations related to energy output, size, beam quality, and operational costs. Energy Limitation: The maximum energy Betatrons can impart to particles is limited. Due to design constraints and practical considerations, they may not achieve as high energies as other types of particle accelerators such as linear accelerators or synchrotrons.Size and Complexity: Despite being more compact than linear accelerators, Betatrons still require a large infrastructure, including the electromagnet and vacuum chamber. This can limit their practicality for certain applications where space is limited or where portability is desired.Fixed Energy Output: Betatrons typically operate at a fixed energy output determined by the design of the electromagnet and vacuum chamber. Unlike synchrotrons, Betatrons cannot easily change their energy output during operation.Radiation Hazard: Betatrons produce high-energy electron beams, which can pose radiation hazards if not properly shielded and controlled.Beam Quality: Betatrons may have limitations in beam quality, including beam stability, divergence, and energy spread. These factors can affect the accuracy and precision of experiments or applications using electron beam produced by the them.Maintenance and Operating Costs: Maintaining and operating Betatrons can be costly due to its complex equipment involved, including the electromagnet, vacuum system, and associated control systems. Professor Donald Kerst built the worlds first magnetic induction accelerator in 1940. The betatron weighed in at just under four tons and required about 30 kilowatts to run. Branded as the Worlds Most Powerful X-Ray Machine, the betatron could accelerate electrons at speeds of more than 158,000 miles per second and give them an energy of more than 2.5 million electron volts. At the time, this was the highest velocity ever produced by any machine. The images produced by the betatron were described by Arthur Wildhagen of Scientific American as knife-sharp (1943). The betatron operates by giving the electrons inside the vacuum tube a continuous push using a magnetic field, which allows them to attain their great speed and energy.Professor Kerst making an adjustment on the first betatron, University of Illinois, 1940The original Betatron was called many different names, ranging from rheotron and inductron to Super X-ray Machine and cosmic ray machine. Eventually, Professor Kerst held a departmental competition. After receiving many entries, one of the most interesting being: Ausserordentlichhochgeschwindigkeitelektronenentwickelndenschwerarbeitsbeigollitron, which roughly translates as Hard working by golly machine for generating extraordinarily high-velocity electrons. Kerst eventually decided on betatron. Professor Kerst poses with the Original Betatron, University of Illinois, 1941From the beginning, Professor Kerst identified three major applications for later incarnations of the betatron: 1) For industry, a powerful source of X-rays of 20 to 30 million volts energy; 2) For medicine, a source of x-rays or for an electron beam for use against cancer and other malignant tissues; and 3) For scientific research, a powerful X-ray and electron source with precision control, and a laboratory source of cosmic rays, produced at energies of 250 million volts or more.As with many devices of the day, the later incarnations of the Betatron captured the militarys interest. A portable version of the betatron, or a baby Betatron, was developed in secret during World War II. Developed by Professor Gerald M. Almy, while Professor Kerst was away working on the atomic bomb, this Betatron could generate radiation equal to that of 3 grams of radium at one-tenth of the price.The betatron had a lasting impact on the design of other atom smashers. Power giant General Electric later built a 100 million volt betatron for personal use, but researchers at the time believed it had little practical application beyond the field of physics. Loomis Laboratory. 25 MeV Betatron located in the northwest corner near the study tables. Department of Physics. (2013). Physics in the 1940s: The Betatron. Retrieved on February 11th, 2013 from Kerst and the Betatron. 1946. Photograph Subject File, 1868-, Record Series 39/2/20, Box 120, Folder ENG 10-3 Phyiscs Laboratories. University of Illinois Archives.Kingery, R. A., Berg, R. D., & Schillinger, E. H. (1967). Men and Ideas in Engineering. University of Illinois Press: Urbana.Kerst, D. W. Development of the Betatron and Its Place in Science. From Talk Given at Dedication of Betatron, United States Army Arsenal, Picatinny, New Jersey, Record Series 11/10/12, Box 14, University of Illinois Archives.Wildhagen, A.R. (May, 1943). The Betatron. Scientific American, Record Series 11/10/12, Box 4, University of Illinois Archives.Worlds First Betatron. (October 1966). Photograph Subject File, 1868-, Record Series 39/2/22, Box 120, Folder ENG 10-2 Physics Faculty. University of Illinois Archives.Wright, J. (Sun, Apr. 14, 1943). Baby Betatron. University of Illinois News. Download the Testbook APP & Get Pass Pro Max FREE for 7 Days10,000+ Study NotesRealtime Doubt Support71000+ Mock TestsRankers Test Series+ more benefitsDownload App NowCyclic particle acceleratorOne of the first betatrons built by Donald Kerst (visible right) at University of Illinois, 1940. Its 4-ton magnet could accelerate electrons to 24MeV.A German 6MeV betatron (1942)A 35MeV betatron used for photonuclear physics at the University of Melbourne.A betatron is a type of cyclic particle accelerator for electrons. It consists of a torus-shaped vacuum chamber with an electron source. Circling the torus is an iron transformer core with a wire winding around it. The device functions similarly to a transformer, with the electrons in the torus-shaped vacuum chamber as its secondary coil. An alternating current in the primary coils accelerates electrons in the vacuum around a circular path. The betatron was the first machine capable of producing electron beams at energies higher than could be achieved with a simple electron gun, and the first circular accelerator in which particles orbited at a constant radius.[1]The concept of the betatron had been proposed as early as 1922 by Joseph Slepian.[2] Through the 1920s and 30s a number of theoretical problems related to the device were considered by scientists including Rolf Wideroe,[3][4] Ernest Walton, and Max Steenbeck.[5] The first working betatron was constructed by Donald Kerst at the University of Illinois Urbana-Champaign in 1940.[6][7][8]After the discovery in the 1800s of Faraday's law of induction, which showed that an electromotive force could be generated by a changing magnetic field, several scientists speculated that this effect could be used to accelerate charged particles to high energies.[2] Joseph Slepian proposed a device in 1922 that would use permanent magnets to steer the beam while it was accelerated by a changing magnetic field.[9] However, he did not pursue the idea past the theoretical stage.In the late 1920s, Gregory Breit and Merle Tuve at the Bureau of Terrestrial Magnetism constructed a working device that used varying magnetic fields to accelerate electrons. Their device placed two solenoidal magnets next to one another and fired electrons from a gun at the outer edge of the magnetic field. As the field was increased, the electrons accelerated in to strike a target at the center of the field, producing X-rays. This device took a step towards the betatron concept by shaping the magnetic field to keep the particles focused in the plane of acceleration.[2]In 1929, Rolf Wideroe made the next major contribution to the development of the theory by deriving the Wideroe Condition for stable orbits. He determined that in order for the orbit radius to remain constant, the field at the radius must be exactly half of the average field over the area of the magnet. This critical calculation allowed for the development of accelerators in which the particles orbited at a constant radius, rather than spiraling inward, as in the case of Breit and Tuve's machine, or outward, as in the case of the cyclotron.[10] Although Wideroe made valuable contributions to the development of the theory of the Betatron, he was unable to build a device in which the electrons orbited more than one and a half times, as his device had no mechanism to keep the beam focused.[2]Simultaneously with Wideroe's experiments, Ernest Walton analyzed the orbits of electrons in a magnetic field, and determined that it was possible to construct an orbit that was radially focused in the plane of the orbit. Particles in such an orbit which moved a small distance away from the orbital radius would experience a force pushing them back to the correct radius.[2] These oscillations about a stable orbit in a circular accelerator are now referred to as betatron oscillations.[10]In 1935 Max Steenbeck applied in Germany for a patent on a device that would combine the radial focusing condition of Walton with the vertical focusing used in Breit and Tuve's machine.[5] He later claimed to have built a working machine, but this claim was disputed.[2]The first team unequivocally acknowledged to have built a working betatron was led by Donald Kerst at the University of Illinois. The accelerator was completed on July 15, 1940.[7]In a betatron, the changing magnetic field from the primary coil accelerates electrons injected into the vacuum torus, causing them to circle around the torus in the same manner as current is induced in the secondary coil of a transformer (Faraday's law).The stable orbit for the electrons satisfies 0 = 2 r 0 2 H 0 , {\displaystyle \theta _{0}=2\pi r_{0}^{2}H_{0},} where 0 {\displaystyle \theta _{0}} is the flux within the area enclosed by the electron orbit, r 0 {\displaystyle r_{0}} is the radius of the electron orbit, and H 0 {\displaystyle H_{0}} is the magnetic field at r 0 {\displaystyle r_{0}} .In other words, the magnetic field at the orbit must be half the average magnetic field over its circular cross section: H 0 = 1 2 0 r 0 2 . {\displaystyle \Leftrightarrow H_{0}={\frac {1}{2}}{\frac {\theta _{0}}{\pi r_{0}^{2}}}.} This condition is often called Widere's condition.[11]The name "betatron" (a reference to the beta particle, a fast electron) was chosen during a departmental contest. Other proposals were "rheotron", "induction accelerator", "induction electron accelerator",[12] and even "Auerordentlichehochgeschwindigkeitselektronenentwickelndesschwerarbeitsbeigollitron", a suggestion by a German associate, for "Hard working by golly machine for generating extraordinarily high velocity electrons"[13][14] or perhaps "Extraordinarily high velocity electron generator, high energy by golly-tron."[15]Betatrons were historically employed in particle physics experiments to provide high-energy beams of electronsup to about 300 MeV. If the electron beam is directed at a metal plate, the betatron can be used as a source of energetic x-rays, which may be used in industrial and medical applications (historically in radiation oncology). A small version of a betatron was also used to provide a source of hard X-rays (by deceleration of the electron beam in a target) for prompt initiation of some experimental nuclear weapons by means of photon-induced fission and photofission in the bomb core.[16][17][18]The Radiation Center, the first private medical center to treat cancer patients with a betatron, was opened by Dr.O.Arthur Stiennon in a suburb of Madison, Wisconsin in the late 1950s.[19]The maximum energy that a betatron can impart is limited by the strength of the magnetic field due to the saturation of iron and by practical size of the magnet core. The next generation of accelerators, the synchrotrons, overcame these limitations.^ "Betatron | particle accelerator". Encyclopedia Britannica. Retrieved 2019-01-24.^ a b c d e f Kerst, Donald W. (January 1946). "Historical Development of the Betatron". Nature. 157 (3978): 9095. Bibcode:1946Natur.157...90K. doi:10.1038/157090a0. PMID21015096. S2CID42153256.^ Widere, R. 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March 20, 1950. p.131.^ Big Science: The Growth of Large-Scale Research, ISBN978-0-8047-1879-0.^ Nuclear Weapons Archive, Tumbler shot series, item George.^ Nuclear Weapons Archive, Elements of Fission Weapon Design, section 4.1.8.2.^ Wisconsin alumnus, Volume 58, Number 15 (July 25, 1957).Wikimedia Commons has media related to Betatrons.The Betatron at UIUCRetrieved from " By Gk Scientist Betatron is a circular particle accelerator to accelerate electrons to extremely high energies up to 300 MeV. It was invented by D. W. Kerst. It is different from cyclotron in two fundamental respects- The electrons are accelerated by an expanding magnetic field.The circular orbit of the electron has a constant radius. The principle of betatron is similar to that of the transformer, i.e., it is mutual induction. The primary current produces an oscillating magnetic field which, in turn, induces an oscillating potential in the secondary coil. In betatron, a magnetic field is produced in electro-magnets (i.e. primary coil) while the cloud of electrons, located inside the doughnut-shaped vacuum chamber, takes the place of secondary windings. The magnetic field has two effects on the electron which is injected into the doughnut, Due to changing magnetic flux additional energy is provided to electron i.e. central flux (which is due to an electromotive force).A radial force (i.e. guide field/lines) is produced by the action of a magnetic field (perpendicular to the velocity of an electron) which keeps the electron in a fixed orbit. Doughnut Chamber- It is a specially shaped, highly evacuated glass tube.The doughnut chamber is placed between the specially shaped poles of an electromagnet which is excited by an alternating current usually of frequency 80 to 180 Hz. The magnetic field is normal to the plane of the doughnut so that a changing magnetic flux threads the equilibrium orbit.The high-velocity electrons from the electron gun are injected into the doughnut when the central main flux is rising in one direction i.e. at the beginning of each cycle. Electrons from the electron gun are injected into the doughnut chamber when the magnetic field is just rising from its zero value in the 1st quarter cycle (see fig. C).As the magnetic field builds up during this part of the cycle, it induces an emf inside the doughnut and accelerates the electrons which are already moving in a circular path by the action of the transverse magnetic field.When current increases from zero to its peak value, an increasing flux is suddenly stopped and high-energy electrons leave their path to strike a target. Let r be the radius of the circular orbit of an electron which is moving in a doughnut vacuum chamber, under the action of a magnetic field.B = magnetic field at any instant. = total magnetic flux through orbit.The increase in flux due to changing magnetic field is d/dt. According to Faradays Law, emf induced = d/dt .(i)(Whenever there is a change in a magnetic field, an emf is induced in the coil and opposes the magnetic field which produces it). Work done on an electron in one revolution is,W = charge x emf induced = e d/dt .(ii)Equation (ii) is also called energy gained by electron in one revolution.Work done is also the product of tangential force F acting on the electron and length of the orbit. W = F x Distance = F x 2r .(iii)i.e. W = e d/dt = F x 2r F = (- e/2r) d/dt .(iv)This force increases the energy of electron and tends to change the radius r. Thus to maintain the r constant this force must be counterbalanced, which is obtained as follows.For the circular motion of electron,Be = m2/r m = Ber .(v)According to Newtons 2nd law, F = d(m)/dt = d(Ber)/dt = er dB/dt .(vi)Thus for r to be constant, equations (iv) and (vi) must be numerically equal i.e.(e/2r) d/dt = er dB/dt d/dt = 2r2 dB/dtor = 2r2B .(vii)This is called the betatron condition, which shows that total flux must be twice the value which would be obtained if B were uniform over the whole area of orbit.Note: (i) Equation (iv) stands for force due to central flux which increases the energy of an electron.(ii) Equation (vi) stands for force due to guide field/lines which keeps radius of electron constant. When an electron is accelerated, it acquires a very high speed nearly equal to the velocity of light i.e. cNow we have, Be = m2/r m = Berand Emax = mc2 = mc = Berc Emax = Berc .(i)Energy gained per revolution = Emax/Total no. of revolutions .(ii)and Total no. of revolutions, N = Total distance travelled/Distance travelled in one revolution N = (velocity x time)/2r = (c x t/4)/2r = (c x 1/4f)/2r N = c/4f x 1/2r .(iii)

Explain the construction and working of betatron. Betatron principle construction working. Principle of betatron.