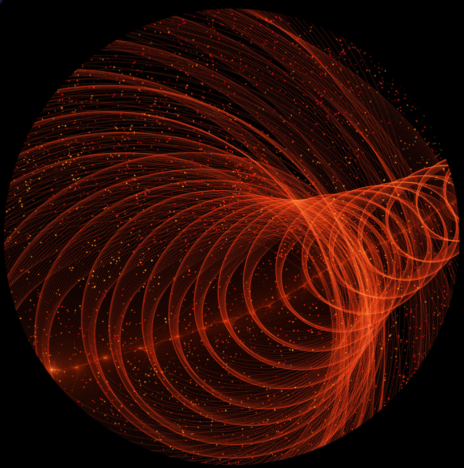
Department Of Physics

NEWSLETTER



November 2023 Issue

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EDITOR'S NOTE

Greetings, dear readers!

I am excited and honoured to welcome you to the first newsletter issue under my editorship. This time, we have curated the newsletter as a combination of various themes in Atomic Physics, along with some exciting developments and background information on a new movie!

In this newsletter issue, we take a deep dive into the fascinating field of atomic physics, how it dances with astrophysics and explore the latest buzz in pop culture, namely the release of the biopic on the father of the Atomic Bomb – Robert J Oppenheimer, and India's newest scientific achievement – the landing of Chandrayaan-3 on the South Pole of the Moon. Science has never been more exciting! Additionally, we feature an interview with a Masters's student who had the opportunity to intern in Europe. Read on to find out more!

We remain committed to providing high-quality, engaging, and relevant content as we move forward. We strive to exceed your expectations and look forward to your continued readership. Your enthusiasm and support motivate us to explore new horizons and bring you the best in every issue. Here's to a wonderful first issue!

Warm regards,

Tina Garg
Editor
Department of Physics
IIT Bombay

ATOMIC ADVENTURES: UNVEILING THE MYSTERIOUS REALM

Ah, atomic physics! A rather interesting field. Many enjoyed this chapter in high school, but few go on to study this in minuscule detail (pardon the pun, it was intended). Will this serious but fun-to-read article have all it takes to fill in the atomic gaps in your knowledge? Only one way to know!

Chapter 1: The Quest Begins

In the enigmatic world of atomic physics, where radiation dances, nuclear secrets are concealed, uncertainty reigns, and particles morph into waves, the journey is both a labyrinth and a treasure hunt. This captivating voyage has a history stretching across the annals of time. Let's embark on Part 1 of our exploration, diving deep into the unfolding narrative that spans millennia.

The Pivotal Question:

Our story unfolds eons ago when the great philosophers pondered a question that would shape the course of history: "How is the world around us constructed?"

Two distinct notions emerged, each with its devout followers. The first posited that matter was an unbroken continuum, infinite and omnipresent, capable of assuming myriad forms, divisible into ever smaller fragments without end. It was akin to imagining matter as smooth and fluid as water or a generous slab of butter.

In stark contrast, a radical idea took root, suggesting that matter was composed of discreet, indivisible units, much like bricks assembling a sturdy wall. Democritus, circa 400 BC, championed this concept, while Indian scholars like Rishi Kanad, circa 600 or 200 BC, coined the terms 'atomos' and 'anu,' respectively, to describe these elemental entities. However, since venturing into the atomic realm was inconceivable at the time, this notion had but a handful of fervent believers. Among them were notable figures from the Middle Ages, including Francois Bernier, Walter Charleton, Robert Boyle, and the venerable Isaac Newton. (Notably, Newton's attention was diverted by the allure of gravity, and the diminutive atomic forces remained in the shadows.)

Unravelling Thermodynamics:

Fast forward to the 17th and 18th centuries, when the field of thermodynamics began to take shape, owing its very existence to the atomic hypothesis. The kinetic theory, founded on the bedrock of atomic thought, gave rise to the ideal gas equation, bestowing a tangible essence upon temperature—a concept previously shrouded in abstraction.

Enter the Van der Waals equation, a modification of the ideal gas equation that accounted for the volume occupied by gas molecules and the interactions between them. Intriguingly, even before the discovery of charged particles within atoms, the presence of an energy exchange between these atomic entities was known during Van der Waals' era.

The Atomic theory, a silent but powerful player in this unfolding drama, played a pivotal role in establishing the fundamental gas laws that, in turn, fuelled the development of steam engines, refrigeration systems, and the marvels of modern transportation.

And so, our atomic odyssey begins, filled with mysteries waiting to be unravelled and adventures that will challenge our understanding of the universe itself.

Chapter 2: The Atom Unveiled

Enter Dalton:
As our journey through the atomic frontier continues, we encounter the pioneers who dared to decipher the enigma of the atom.

Among them stands John Dalton, a chemist of keen intellect and unwavering curiosity. In the year 1803, he penned his Atomic Theory, an intellectual milestone that reshaped the very essence of matter.

Dalton's inspiration emanated from an Irish chemist named Bryan Higgins. Higgins believed that an atom was a substantial central entity enveloped by a shroud of caloric—a mysterious substance thought to be heat's essence in those times. The atom's size was determined by the expanse of this caloric aura. Intriguingly, while privy to Bryan's theory, Dalton adopted strikingly similar concepts and terminology but omitted any acknowledgement of Bryan's groundbreaking caloric model.

Dalton's theory is distilled down to five fundamental postulates:

a. Elements consist of minuscule particles known as atoms.
b. Atoms of a given element are identical in size, mass, and other characteristics; atoms from distinct elements vary in size, mass, and properties.
c. Atoms cannot be subdivided, created, or annihilated.
d. Atoms from different elements unite in simple whole-number ratios to form chemical compounds.
e. In chemical reactions, atoms amalgamate, segregate, or rearrange.

Dalton's theory illuminated the path for chemists, enabling them to derive fundamental laws such as the law of definite proportions and the law of multiple proportions. Beyond his contributions to chemistry, Dalton extended his hand to the field of metrology and championed the cause of colour-blind individuals like himself.

Journeying Deeper:

a. Discovery of the Electron:

The story takes an electrifying twist in 1859 when German physicist Julius Plücker while exploring electrical conductivity in rarefied gases, observed a mesmerizing phenomenon. The radiation emanating from the cathode triggered phosphorescent illumination on the tube's inner walls when a magnetic field was applied.

Plücker's student, Johann Wilhelm Hittorf, added another layer to this enigma by discovering that a solid body interposed between the cathode and phosphorescent glow cast a shadow. He inferred the existence of straight rays emitted from the cathode, which struck the tube walls, giving rise to the phosphorescence—these rays were christened as Cathode Rays.

In the 1870s, Sir William Crookes, an English chemist and physicist, introduced the first cathode-ray tube boasting a high vacuum. In a startling revelation in 1874, he demonstrated that cathode rays possessed momentum by deflecting a small paddle wheel placed in their path. Crookes further showcased their deflection through the application of a magnetic field, underscoring their behaviour as negatively charged entities.

Enter J.J. Thomson in 1897, who, after studying what were then known as Lenard rays, made an astonishing discovery. He determined that these rays, despite their diminutive size, could traverse considerable distances through air. His experiments not only established that cathode rays were over 1,000 times lighter than hydrogen atoms but also that their mass remained consistent across various types of atoms, indicating that they came from a fundamental entity inside all atoms.

Thomson initially named these particles "corpuscles," but the name "electron," proposed earlier by George Johnstone Stoney in 1891, ultimately gained acceptance. The discovery of the electron thrust physicists deeper into the atom's mystique, sparking discussions about charged particles, forces, and potential energies within these atomic realms.

b. The Emergence of the Nucleus:
J.J. Thomson's famous plum pudding model of the atom suggested that electrons were dispersed randomly within a sphere of positive charge. However, it was a subsequent experiment by Ernest Rutherford, in collaboration with Hans Geiger and Ernest Marsden, that would shake the foundations of atomic theory. They directed alpha particles at a thin sheet of metal foil, anticipating minimal deflections if Thomson's model held true. To their astonishment, many particles veered significantly from their expected path. The revelation that alpha particles, with their considerable mass and velocity, could be deflected to such a degree led to a fundamental reassessment.

Ernest Rutherford proposed a revolutionary concept—a nuclear atom. According to this model, the atom featured a dense core of positive charge at its centre, now known as the nucleus, surrounded by electrons in orbit.

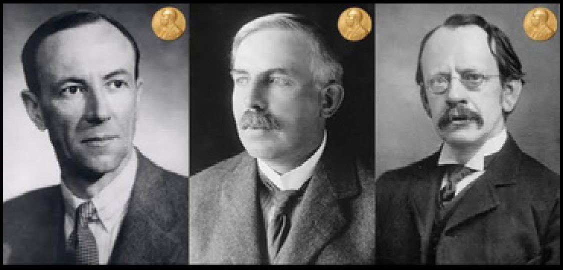
c. Finding Neutrons:
Fast-forward to 1930, when Walther Bothe and Herbert Becker in Germany made a perplexing discovery. They noticed that when energetic alpha particles from polonium collided with certain light elements like beryllium, boron, or lithium, an extraordinarily penetrating radiation emerged. This radiation appeared immune to electric fields, initially suggesting gamma radiation.

Enter Joliot-Curie and Frédéric Joliot in Paris, who revealed that this mysterious radiation expelled high-energy protons when directed at hydrogen-rich materials like paraffin wax. This revelation posed a logical conundrum—gamma rays, with their properties, shouldn't scatter massive protons. James Chadwick quickly performed a series of experiments showing that the gamma ray hypothesis was untenable. Chadwick, J.E.R. Constable, and E.C. Pollard had already conducted experiments on disintegrating light elements using alpha radiation from polonium

They had also developed more accurate and efficient methods for detecting, counting, and recording the ejected protons. Chadwick repeated the creation of the radiation using beryllium to absorb the alpha particles: 9Be + 4He (α) → 12C + 1n. He aimed the radiation at paraffin wax, a hydrocarbon high in hydrogen content, hence offering a target dense with protons.

As in the Paris experiment, the radiation energetically scattered some of the protons. Chadwick measured the range of these protons, and also measured how the new radiation impacted the atoms of various gases.He found that the new radiation consisted of not gamma rays, but uncharged particles with about the same mass as the proton. These particles were named as neutrons.

And thus, as we journey deeper into the atomic labyrinth, we encounter James Chadwick, a student of Rutherford, who, in turn, had learned from Thomson—a lineage of scientific inquiry stretching across generations, propelling us further into the heart of the atom's mysteries



J. Chadwick 1891-1974 | E. Rutherford 1871-1937 | J. J. Thomson 1856-1940

Chapter 3: The Wave Nature Unveiled

The De Broglie Hypothesis:
In our quest to uncover the mysteries of the atom, we delve into the realm of waves and particles, where the boundaries between the two blur into a dance of duality. Just as Einstein had postulated the particle nature of electromagnetic waves, French physicist Louis de Broglie stepped onto the stage of quantum physics in 1924 with a daring proposal—matter, too, could behave as waves. These elusive matter waves came to be known as de Broglie waves.

At the heart of this revelation lay the de Broglie wavelength, symbolized as λ, which became the signature of particles in motion. It was elegantly tied to a particle's momentum, p, through the constant of the quantum world, Planck's constant, h:

$$\lambda = \frac{h}{p}$$

The wave-like character of matter first revealed itself through the eyes of pioneers like George Paget Thomson and Alexander Reid, who conducted a groundbreaking transmission diffraction experiment. Simultaneously, in the Davisson–Germer experiment, electrons took centre stage, independently affirming their wave-like nature.

This profound insight extended beyond electrons, encompassing other elemental particles, neutral atoms, and even molecules.

The Schrödinger Equation:

As the revelation that matter possessed a dual nature—both particle and wave—spread like wildfire, a new challenge emerged. A wave equation was needed to encapsulate this behaviour, and the maestro of quantum mechanics, Erwin Schrödinger, rose to the occasion. In 1926, he unveiled the Schrödinger Equation, a mathematical masterpiece that would become the cornerstone of quantum mechanics:

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + \hat{V}\Psi$$

This equation elegantly described the evolution of quantum states over time, incorporating factors such as the wave function Ψ, Planck's constant $\hbar$, particle mass (m), and the potential energy ($\hat{V}$) acting on the particle.

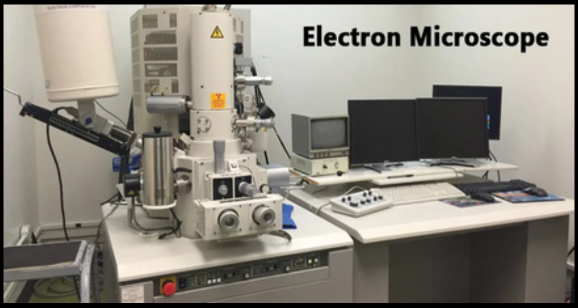
In this journey into the subatomic world, we encounter a remarkable family legacy—a tale of discovery that spans generations. J.J. Thomson, the trailblazing discoverer of electrons as particles, passed the torch to his son, George Thompson, who, in turn, unveiled electrons as waves—a testament to the ever-evolving nature of scientific inquiry.

Practical Application: The Electron Microscope:

The interplay between matter's duality, and its propensity to behave as both particle and wave finds a crucial application in our quest to explore the microscopic universe. As we venture into the nanoworld, where objects loom ever closer together, we demand unparalleled precision from our microscopes.

Enter the electron microscope, a marvel of modern science. To achieve the resolution needed for the tiniest structures, we turn to the De Broglie wavelength, a critical factor. The resolution formula expressed as:

$$r = \frac{0.612\lambda}{n\sin\sin\alpha}$$



Tells us that a smaller wavelength is the key to resolving objects packed closely together. Electrons come to our rescue, imbued with kinetic energy to shrink their De Broglie wavelength to a minimum, making them ideal for electron microscopy.

Here's how it works:

1. The electron gun springs to life, birthing a cascade of electrons.
2. Two sets of condenser lenses funnel these electrons into a razor-thin beam.
3. An accelerating voltage, often between 100 and 1000 kV, propels the electrons down the microscope column.
4. The specimen under scrutiny is no ordinary sample; it's sliced paper-thin, at least 200 times thinner than what optical microscopes handle.
5. As the electron beam pierces the specimen, electrons scatter, their fate determined by the thickness and refractive index of various specimen parts.
6. Denser regions of the specimen scatter more electrons, casting darker shadows on the imaging screen, while transparent areas gleam brightly.
7. The electron beam, now laden with information, moves through the objective lens, which wields immense magnifying power, forming an intermediate image.
8. Ocular lenses then add the final layer of magnification, unveiling the microscopic world in exquisite detail.

In the realm of electron microscopy, two titans reign supreme: the Transmission Electron Microscope (TEM) and the Scanning Electron Microscope (SEM).

And so, our journey into the quantum cosmos continues, revealing a universe teeming with wonders beyond the reach of the naked eye, all thanks to the dual nature of matter—a dance of waves and particles that illuminate the tiniest corners of our existence.

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Kshitij Bahadarpurkar (BTech EP, 2nd year)

THE MANHATTAN PROJECT

Ever seen Oppenheimer and wanted to know more about the physics and research methods adopted during the Manhattan Project? The movie may have taught us more about Oppenheimer as a person, but this intense article will certainly have you knowing more about the processes involved in this Promethean feat!

The Beginning:

The entire chain of events began with an unexpected discovery by researchers in Nazi Germany just before Christmas 1938 radically changed the direction of both theoretical and practical nuclear research. In their Berlin laboratory, the radiochemists Otto Hahn and Fritz Strassmann found that when they bombarded uranium with neutrons, the uranium nucleus split into two radioactive isotopes of fission while releasing secondary neutrons and an enormous amount of energy. The possible military uses that might be derived from the fission of uranium atoms were not lost on the best and brightest of the world's physicists. In August 1939, Einstein, with the help of Hungarian émigré physicist Leo Szilard, wrote a letter to President Roosevelt, informing him that recent research showed that a chain reaction in a large mass of uranium could generate vast amounts of power. This could conceivably lead, Einstein wrote, to the construction of "extremely powerful bombs." A single bomb, the physicist warned, potentially could destroy an entire seaport. Einstein called for government support in uranium research, noting darkly that Germany had stopped the sale of uranium and German physicists were engaged in uranium research.

However, the initial response was quite tepid. No one knew whether an atomic bomb was even possible, let alone within the timeframe of the war. Further, researchers knew that they needed the elusive uranium-235, extracting enough quantities of which would be very costly and time-consuming, hardly possible in the required time. Not until 1942, after the Japanese attack on Pearl Harbor had thrust the United States into World War II, was the decision made to proceed with a full-scale program to build an atomic bomb. The atomic bomb project was placed under the Army Corps of Engineers. The Corps set up the Manhattan Engineer District commanded by Brigadier General Leslie R. Groves. Groves located the production facilities for uranium-235 in Tennessee. He also set up two plutonium separation facilities in Tennessee and Washington (the state, not the city. Yeah, the US naming scheme is weird). Much of the research work on producing plutonium, including the design of the piles, took place at the Metallurgical Laboratory (Met Lab) in Chicago. Design and fabrication of the first atomic bombs were the responsibility of the newly established Los Alamos Scientific Laboratory, located at a virtually inaccessible site high on a mesa in northern New Mexico.

General Leslie R. Groves. Reprinted from Vincent C. Jones, *Manhattan: The Army and the Atomic Bomb* (Washington, D.C.: U.S. Government Printing Office, 1985).

Next steps - Isotope Separation – The Physics Problems

Since uranium-235 and uranium-238 were chemically identical, they could not be separated by chemical means. And with their masses differing by less than one percent, separation by physical means would be extremely difficult and expensive. Nonetheless, scientists pressed forward with several complicated techniques of physical separation, all based on the small difference in atomic weight between the uranium isotopes. Groves placed two of these methods in production in Tennessee.

The 'electromagnetic method', pioneered by Alfred O.C. Nier of the University of Minnesota, used a mass spectrometer, or spectrograph, to send a stream of charged particles through a magnetic field. Atoms of the lighter isotope would be deflected more by the magnetic field than those of the heavier isotope, resulting in two streams that could then be collected in different receivers. The other method, 'gaseous diffusion' was based on the well-known principle that molecules of a lighter isotope would pass through a porous barrier more readily than molecules of a heavier one. This approach proposed to produce by myriad repetitions a gas increasingly rich in uranium-235 as the heavier uranium-238 was separated out in a system of cascades.

The first goal on the path to large-scale plutonium production would be to show that a self-sustaining chain reaction could be created and controlled. To this end, Enrico Fermi began moving his Columbia 'pile-research group' to Chicago in early 1942 to join forces with Samuel Allison's group. A serious issue was supply of critical materials. A chain-reacting pile would require several tons of uranium and hundreds of tons of graphite, both as pure as possible and with the uranium preferably in the form of pure metal as opposed to an oxide. On December 2, 1942, after about a month of around the clock construction, the first critical pile of uranium was constructed, and Fermi successsfully demonstrated the first self-sustaining nuclear reaction.

After the success of the setup, work began on the 'X-10' codenamed pilot-scale pile. X-10 would have multiple missions: to produce plutonium to test chemical separation procedures and supply Los Alamos with fissile material for research, to train operating personnel for the eventual production-scale reactors, to serve as a platform for instrument development and cross-section research, and to conduct radiation-damage and biological radiation-effects studies. A reactor fueled with natural uranium produces about 0.76 g of plutonium per day per megawatt (MW) of power produced, a mere one-third of the mass of a dime. If X-10 were to run for a full year at its 1,000 kW (=1 MW) rating, it would theoretically produce about 275 g of plutonium, assuming perfect chemical separation efficiency. It ultimately achieved better than this.

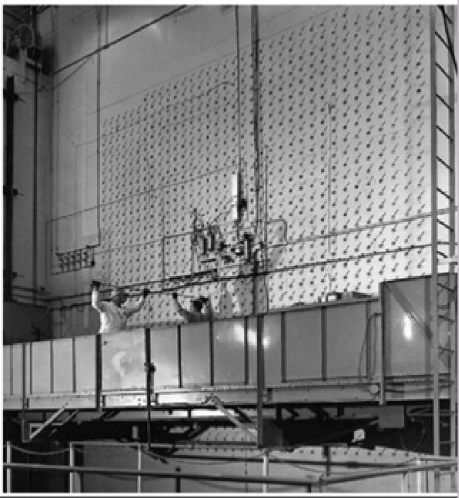


Fig. 5.8 Front face of the X-10 pile. *Source* http://commons.wikimedia.org/wiki/File:X10_Reactor_Face.jpg

The Los Alamos Laboratory and Dr. J. Robert Oppenheimer

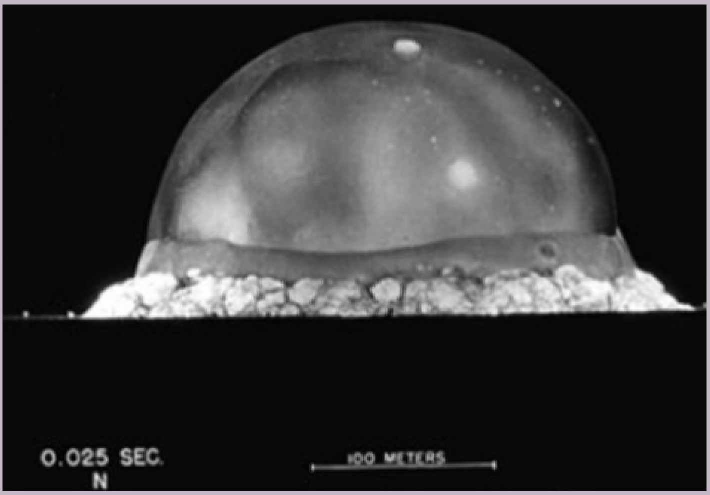
The final link in the Manhattan Project's far flung network was the Los Alamos Scientific Laboratory in Los Alamos, New Mexico. When work began at Los Alamos, the properties of uranium were reasonably well understood, those of plutonium less so, and knowledge of fission explosions entirely theoretical. In addition to calculations on uranium and plutonium fission, chain reactions, and critical and effective masses, work needed to be done on the ordnance aspects of the bomb, or "gadget" as it came to be known. Two subcritical masses of fissionable material would have to come together to form a supercritical mass for an explosion to occur. Furthermore, they had to come together in a precise manner and at high speed. Measures also had to be taken to insure that the highly unstable subcritical masses did not predetonate because of spontaneously emitted neutrons or neutrons produced by alpha particles reacting with lightweight impurities. The chances of predetonation could be reduced by purification of the fissionable material and by using a high-speed firing system capable of achieving velocities of 3,000 feet per second. A conventional artillery method of firing one subcritical mass into the other was under consideration for uranium-235, but this method would work for plutonium only if absolute purification of plutonium could be achieved, which was highly doubtful.

Bomb designers, unable to solve the purification problem, turned to the relatively unknown implosion method for plutonium. With implosion, symmetrical shockwaves directed inward would compress a subcritical mass of plutonium packed in a nickel casing (tamper), releasing neutrons and causing a chain reaction.

The SUPER
While research on the fission bombs were being carried out, always in the background loomed the hydrogen bomb, a thermonuclear device considerably more powerful than either a uranium or plutonium device but one that needed a nuclear fission bomb as a detonator. Research on the hydrogen bomb, or Super, was always a distant second in priority at Los Alamos, but Oppenheimer concluded that it was too important to ignore. After considerable thought, he gave Teller permission to devote himself to the Super. To make up for Teller's absence, Rudolf Peierls, one of a group of British scientists who reinforced the Los Alamos staff at the beginning of 1944, was added to Bethe's theory group in mid-1944. Another member of the British contingent was the Soviet agent Klaus Fuchs, who had been passing nuclear information to the Russians since 1942 and continued doing so until 1949 when he was caught and convicted of espionage (and subsequently exchanged).

The Trinity Test and Dawn of the Atomic Age

Tower For Trinity Test. Department of Energy



Left: The Trinity Fireballat 25 ms in nuclear age. Right: The Trinity Mushroom Cloud a few seconds later

Weapon design for the uranium gun bomb, 'Little Boy' was frozen in February 1945. Confidence in the weapon was high enough that a test prior to combat use was seen as unnecessary. The design for an implosion device was approved in March with a test of the more problematic plutonium weapon, 'Fat Man' scheduled for July 4, but delayed to July 16. The objectives of the test were to attempt to measure critical aspects of the reaction. Specifically, scientists would try to determine the symmetry of the implosion and the amount of energy released. Additional measurements would be taken to determine damage estimates, and equipment would record the behavior of the fireball. At precisely 5:30 a.m. on Monday, July 16, 1945, the atomic age began. While Manhattan staff members watched anxiously, the device exploded over the New Mexico desert, vaporizing the tower and turning asphalt around the base of the tower to green sand.

The bomb released approximately 18.6 kilotons of power, and the New Mexico sky was suddenly brighter than many suns. Some observers suffered temporary blindness even though they looked at the brilliant light through smoked glass. Seconds after the explosion came a huge blast, sending searing heat across the desert and knocking some observers to the ground. As the orange and yellow fireball stretched up and spread, a second column, narrower than the first, rose and flattened into a mushroom shape, thus providing the atomic age with a visual image that has become imprinted on the human consciousness as a symbol of power and awesome destruction.

At base camp, Bush, Conant, and Groves shook hands. Oppenheimer reported later that the experience called to his mind the legend of Prometheus, punished by Zeus for giving man fire.

He also thought fleetingly of Alfred Nobel's vain hope that dynamite would end wars. The terrifying destructive power of atomic weapons and the uses to which they might be put were to haunt many of the Manhattan Project scientists for the remainder of their lives.4

The Droppings

The success of the Trinity test meant that a second type of atomic bomb could be readied for use against Japan. In addition to the uranium gun model, which was not tested prior to being used in combat, the plutonium implosion device detonated at Trinity now figured in American Far Eastern strategy. In the end Little Boy, the untested uranium bomb, was dropped first at Hiroshima on August 6, 1945, while the plutonium weapon Fat Man followed three days later at Nagasaki on August 9.

(Little Boy being loaded into the bomb bay of a B-29 bomber.)

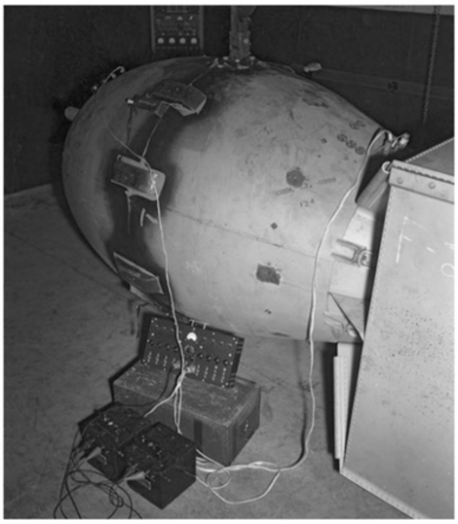


Fig. 4.3 The Nagasaki *Fat Man* plutonium implosion weapon shortly before its mission. *Fat Man* was 12 ft long, 5 ft in maximum diameter, and weighed 10,300 lb when fully assembled (Sublette 2007) (Photo courtesy Alan Carr, Los Alamos National Laboratory)

Bomb After-Affects

The three main damaging effects of nuclear weapons on people and structures are pressure (''blast''), thermal radiation (heat), and fallout. Despite no theoretical formulae avialable, for pedagogical purposes, however, we can use some approximate relations to make order-of-magnitude estimates, assuming clear skies, an airburst weapon, and flat terrain.

The majority of the physical destruction caused by nuclear weapons is due to the high-pressure shock wave that races out from the fireball. Normal atmospheric pressure is 14.7 pounds per square inch (psi). Weapons effects are usually stated in terms of the overpressure created, which is the number of psi generated in excess of this ambient value. Seemingly small overpressures can have devastating effects. An overpressure of 1 psi is sufficient to break ordinary glass windows. Wood frame homes are destroyed under the action of a 5 psi overpressure, which is also about the threshold for human eardrum rupture.

Massive multistory buildings will sustain moderate damage at 6–7 psi overpressure and be demolished at 20 psi. The threshold for human death from compressive effects sets in at about 40 psi. At a “slant range” - the direct line-of-sight distance between the explosion and the observer - of 2 miles from a 20-kiloton yield, the overpressure is approximately 2.2 psi. Your house will be damaged, but likely survive—as will you, if you can avoid flying debris, fallout, and thermal burns. At two miles, a 400-kiloton yield will give an overpressure of nearly 10 psi.

The unit of measure used to quantify flash burns is the number of calories of energy deposited per square centimeter of skin (cal/cm2). The resulting burns themselves are classified as first, second, or third degree. For a fairly low-altitude airburst of a 20-kt bomb, at a slant range of 2 miles, you will easily have second-degree burns. It has been estimated that at Hiroshima, some two-thirds of those who died in the first day after the bombing were badly burned. A 400-kiloton bomb at two miles will be fatal; you will literally be burnt alive.

For many people, the most feared consequence of a nuclear explosion is exposure to radioactivity. In reality, however, for most victims of a nuclear attack, the radiation exposure will likely pale in comparison to pressure and heat effects: if you are near enough to suffer acute radiation exposure, you have probably been blasted or burnt to death.

The demarcation time between the two is not defined and any hard-and-fast way, but one minute after the explosion is usually taken as a working definition. For our 20-kiloton bomb at 2 miles, the “prompt” dosage - raditaion upto one minute after exposure - is about 0.6 rems, an almost harmless amount; a single-shot lethal dose is about 500 rems. Even so, if you do not receive an acutely harmful dose of radiation, there is a statistical chance that you will in the long-term die from a radiation-induced cancer. It has been estimated that the roughly 100,000 survivors of Hiroshima and Nagasaki received average radiation doses of 20 rems, which implies some 800 excess deaths in the long term. In comparison, the number killed by blast, burns, and acute radiation was on the order of 100,000, with many of those suffering injuries from multiple causes.

Fun exercise - How warm is it?

Would an assembled plutonium bomb core feel warm to the touch? 239Pu is an alpha emitter with a half-life of 24,100 years. As seen in the preceding section, this corresponds to some 2.3 1012 alpha-decays per second per kilogram of material. With alphas of energy 5.2 MeV, the power generated by alpha-decay from a 1-kg mass of 239Pu amounts to P ~ 1.91 W. We can make a rough estimate of how much hotter such a mass would be than the surrounding air by assuming that this power is dissipated in accordance with a semi-empirical expression known as Newton’s Law of Cooling.

This expression states that the rate of heat energy loss P (that is, the power emitted) due to convection by a body of surface temperature T to a surrounding environment at ambient temperature Tamb is given by P ¼ Ah Tð Þ Tamb , ð5:1Þ where A is the surface area of the body and h is an empirical parameter known as the heat transfer coefficient. The value of h depends on the geometry of the object and the properties of the surrounding environment, which is usually a “fluid” such as air or water. For free convection in steady air, h ~ 5–25 W/(m2 K). For a 6.2-kg Trinity/Fat Man core, the alpha-decay rate corresponds to a power output of 11.86 W. If spherical, this mass would have a radius of 4.56 cm and a surface area of 2.61 102 m2 . If we adopt h ¼ 15 W/(m2 K), then (T−Tamb) ~ 30 K, that is, the surface of the core will be some 30 K warmer than the surrounding air. The claim of warmth is certainly credible.

Link to the video of prepping and dropping the bomb - https://www.youtube.com/watch?v=pXD_fzrcE20

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A still from Nolan’s masterclass

Mridul Goel (BTech EP, 3rd year)

RESEARCH ABROAD: NAVIGATING AN INTERNSHIP IN GERMANY

An internship abroad seems exciting and holds immense power in exploring a new place and new parts of yourself. We interviewed Preety, a final-year MSc student to learn more about how she obtained the internship and the internship itself!

Could you tell us a bit about yourself? Where did you grow up? Where did you study before joining IITB? What was your childhood like? What are your hobbies?

Hello! I'm Preety, currently in the final year of my M.Sc. in Physics. My hometown is Jind in Haryana, and I pursued my undergraduate degree at Miranda House, University of Delhi. My childhood was quite adventurous, as my father served in the BSF, which led to frequent transfers. This allowed me to experience various cities across India and immerse myself in diverse cultures.

As for my interests, I have a passion for artistic expression through painting and enjoy dancing to various genres. I also relish the opportunity to engage in sports and physical activities in general. I'm specifically fond of swimming and skating.

Tell us about the internship and the application process. How did you find out about it? What motivated you to apply for it? And what was the preparation like?

I had the privilege of doing my internship at TU Braunschweig in Germany. To get this opportunity, I applied through the Placement Cell at IIT Bombay. After submitting my application, my resume caught the eye of the supervisor, which led to an interview and ultimately got me selected.

I was fortunate to have a senior here who was also my senior at Miranda House. Since she also did a summer internship in Germany, she provided me with valuable insights into the programme.

I have always been curious about research abroad and wanted to see how things are done internationally. Plus, I knew that having a strong resume would be key to getting selected, so I reached out to other seniors as well for advice on how to make my application stand out.

Give us an overview of the research you were involved in. And what was the most exciting part of it?

My research during the internship primarily revolved around the exciting field of photonics. I had the privilege of working on two different projects. The first one was all about waveguides on photonic chips, in which I had to calculate the loss coefficient due to sidewall scattering. The other involves microscope automation, in which I had to write some unique code to make all the parts of the microscope work together smoothly.

The part that really got me pumped up throughout this experience was the subject matter itself. My initial knowledge of photonics was limited only to its name and a basic idea, but this internship presented a golden opportunity for me to dive deeper into this fascinating field. I was on a journey of constant learning and exploration.

You did your internship in Germany, the land of great poets, philosophers and scientists. What was your experience like working there? What was it like to stay in a country that is vastly different from your home country in many aspects?

Did you have the opportunity to collaborate with people from different backgrounds? And how valuable was that?

Indeed, Germany was a whole new world compared to India. My time there felt like a thrilling rollercoaster ride with its ups and downs. There were moments when I wholeheartedly embraced the new environment but there were also instances when I faced challenges.

But given that my stay there was only for two and a half months, I chose to focus on the positive aspects. I immersed myself in the rich culture, engaged with the local community, and savoured the breathtaking natural landscapes that Germany had to offer. This approach helped me to fully appreciate the unique experience of living and working in a foreign land.

Yes, I got to hang out with individuals from all sorts of backgrounds, especially in the dorm. Working with Ph.D. students was a big part of the internship. It was eye-opening and taught m

Did you have any particular expectations before the commencement of your internship? Did you have any prior research experience? What proved to be the most challenging aspect of your project, and how did you navigate through it?

Before starting my internship, I had one main expectation: to learn a lot. The topic of photonics was new to me, so I was eager to soak up as much knowledge as I could during my short stay in Germany. I also hoped to work closely with other researchers and mentors, sharing ideas and experiences. I knew that this experience would not only help me academically but also personally. In simple terms, my big hope was to make the most of this short trip and grow in every possible way.

Yes, I had some prior research experience. While I was an undergrad, I had the opportunity to work on three summer internship projects at the DS Kothari Research and Innovation Centre in Miranda House, collaborating with my professors. Also, I took on some self-initiated projects and worked on course-related projects. My strategy was to explore different fields within physics to help me identify my specific area of interest.

The most challenging phase in any research project often occurs at the beginning, when grasping the main objectives and going through many research papers can be overwhelming. To overcome this initial challenge, I reached out to my supervisor and Ph.D. students, who generously shared their knowledge and guided me through the complexities of the project.

Their support and willingness to explain complex concepts played a crucial part in getting me on the right track.

No, the internship wasn't as demanding as I had initially thought. They treated us as beginners and focused on helping us understand the topic. Their main goal was to guide and teach rather than push us for excessive work. Plus, we had weekends free to travel and explore different cities and countries in Europe, which made the experience enjoyable and balanced.

Do you have a favourite memory or an anecdote from your time there that you can share with us?

I have quite a few memorable moments from my internship, but one that really stands out is when I took a trip to Paris with a broken phone. Here's what happened: My mobile phone's screen got smashed during a trip to Switzerland, and getting it fixed was just too expensive, not to mention buying a new one, which meant that I had to make do with my laptop for communication.This couldn't have been worse because we had also planned on visiting Paris the following week. I usually travelled with two friends who were also interning with me, but one of them had already been there, and the other had to decline for some reason.

But two of my other friends, who were interning in a different part of Germany, were also keen on visiting Paris. So, we decided to meet in Paris. This meant that I had to travel from Braunschweig to Paris and back all by myself, which wasn't supposed to be a big deal except for the fact that my phone was barely working and there was also no way to charge my laptop on the bus. However, I ended up making a new friend during this 'solo' journey and had a wonderful time. Then I finally converged with my other two friends in the city of love and had one of the best times of my life. I experienced an incredible adrenaline rush during that trip!

Another set of cherished memories is regarding our weekend trips. I would cook three meals a day during the week, and on weekends, I'd prepare and pack food for the entire trip. The anticipation, excitement, and preparation for these trips have been etched into my mind forever.

A powerful country, Germany has been at the centre of world affairs for a long time. How did your experience there influence your view of its strength and qualities?

Germany, as a nation with a rich history of poets, philosophers, and scientists, left a profound impact on my perception.

Working there exposed me to the robust academic and research traditions, their commitment to innovation, and the collaborative spirit among researchers. It deepened my appreciation for Germany's contributions to the world stage, both historically and in contemporary times. And the way I see it, it will continue to be a major player in world affairs and will remain an educational destination for many people around the world.

TU Braunschweig, Germany

Recognising the relatively low number of women in research, especially in fields like physics, do you aspire to make a difference in this regard? What advice would you give to young girls, especially in a country like ours, to help them realise their full potential?

I'm super passionate about boosting diversity in research, especially in fields like physics. And honestly, I've never felt like there's been a lack of opportunities for me in this country.

I mean, I love competing head-to-head with the guys when it comes to research stuff. It's all about levelling the playing field. think we should actively get involved in initiatives and support up-and-coming female researchers. It's how we make academia more inclusive.

So, to the young girls in our country, I would advise them to never underestimate their potential and to pursue their passions fearlessly. Seek mentors, believe in your capabilities, and don't be afraid to challenge stereotypes.

Given your experience, could you tell us about your efforts to mentor and guide younger students interested in pursuing a similar career path?

Recently, we organised a seminar-style session with our juniors to share the experiences we gained from our internships. Just as I received guidance from my seniors, I felt a strong desire to give back and assist our juniors in navigating the internship process effectively. In that session, we provided guidance on the application process, emphasised key resume highlights, and shared valuable tips to help them secure worthwhile internships.

What is your mantra in life? Finally, what is your plan for the future?

I have always believed that talent alone is not enough; one has to work extremely hard to achieve success. This is my mantra in life, and I've been striving to stay true to it.

Well, as for my future plans, I must confess they're still evolving. I am in a dilemma about whether to go for research or do something else. But I believe it's important to savour the journey and explore various opportunities until I find a path that aligns best with my goals. So, for now, I'm keeping my options open and enjoying the adventure that life has to offer, one step at a time!

Heirtami Paswet (MSc Physics, 2nd year)

INDIA'S CHANDRAYAAN-3: A TRIUMPH OF LUNAR EXPLORATION

Chandrayaan-3's landing had us all gripped. Those minutes spent waiting and watching, hoping that we would emerge victorious in our quest to become the first country to land on the Moon's South Pole and to learn more about the closest natural body to us in space. But do you know what went on behind the scenes of this wondrous collaboration between hundreds of researchers, engineers and scientists? Let's find out!

In the grand tapestry of humanity's quest for knowledge and exploration, the Moon has been a constant source of fascination and wonder. Its silvery glow in the night sky has beckoned scientists, dreamers, and explorers alike for centuries. In recent years, India has emerged as a formidable contender in lunar exploration, and the Chandrayaan-3 mission stands as a testament to the nation's unwavering commitment to unravelling the lunar mysteries.

Mission Objectives

Chandrayaan-3 embarked on a remarkable lunar exploration journey guided by a trio of overarching objectives. First and foremost, the mission's primary aim was to achieve a safe and precise landing on the Moon's surface, representing a significant leap in India's lunar exploration endeavours. This objective was not only a technological feat but also a symbolic triumph, showcasing India's capabilities on the global stage.

The mission's second objective was to introduce Pragyan, an advanced rover designed to traverse the lunar terrain, conduct a variety of experiments, and transmit invaluable data back to Earth. Pragyan was equipped with a suite of scientific instruments, promising to unveil crucial insights into the Moon's geological and atmospheric conditions. Its mission was to analyse lunar soil, study the Moon's magnetic field, and capture stunning images of the lunar landscape.

The third and equally significant objective was to deploy a lander and rover combination near the Moon's south pole, a region rich in scientific potential. This choice of landing site was deliberate, as the south pole holds water ice in permanently shadowed craters, a valuable resource for future lunar exploration and perhaps even human colonization.

Mission Timeline

The mission's timeline was meticulously orchestrated to ensure each phase unfolded with precision and efficiency. It commenced with a momentous launch on July 14, 2023, from the Satish Dhawan Space Centre in Sriharikota, India. The towering Geosynchronous Satellite Launch Vehicle Mark III (GSLV Mk III) roared to life, propelling Chandrayaan-3 on its journey through the cosmos. The world watched in awe as the spacecraft embarked on its lunar sojourn.

After traversing the vast expanse of space, Chandrayaan-3 successfully entered lunar orbit on August 5, 2023, marking a pivotal milestone in its quest for lunar exploration. This delicate manoeuvre required precision and finesse, as the spacecraft had to navigate through space and align itself with the Moon's gravitational pull. It was a moment of jubilation for the dedicated team of scientists, and engineers who had tirelessly worked on this mission for years.

A defining moment in the mission occurred on August 23, 2023, when the Vikram lander executed a controlled and safe landing near the Moon's south pole.

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The Pragyan rover affectionately dubbed the "Wise Man" in Sanskrit, was designed to roll off the Vikram lander and onto the lunar surface, heralding a new era of exploration. Its scientific instruments were poised to work diligently, analyzing the lunar regolith, conducting experiments, and capturing high-resolution images of the Moon's terrain. Pragyan's mission was to enhance our understanding of the Moon's history, evolution, and resources.

Scientific Endeavors

Chandrayaan-3 was not merely a technological demonstration; it was a scientific odyssey. The rover, Pragyan, was equipped with an X-ray spectrometer, a laser-induced breakdown spectroscope, and a high-resolution camera to facilitate a comprehensive study of the Moon's surface. These instruments aimed to identify minerals, determine the distribution of elements and unravel the mysteries of the lunar crust.

One of the most intriguing aspects of the mission was the search for water ice at the lunar south pole. The discovery of water ice would not only expand our understanding of the Moon's geological history but also pave the way for future lunar colonization efforts. Chandrayaan-3 was poised to contribute significantly to this scientific pursuit.

The study of the Moon's magnetic field was another pivotal aspect of the mission. Pragyan carried a magnetometer to measure the Moon's magnetic anomalies. Understanding the Moon's magnetic properties is essential for comprehending its geological history and could provide insights into the lunar dynamo, which remains a subject of scientific curiosity.

Chandrayaan-3 also aimed to shed light on the Moon's mysterious exosphere. The rover was equipped with an instrument to analyze the Moon's exospheric composition, helping scientists unravel the dynamics of this tenuous lunar atmosphere. This research could have broader implications for our understanding of exospheres on other celestial bodies.

A Beacon of Inspiration

Chandrayaan-3 represented more than a scientific endeavour; it was a beacon of inspiration for generations to come. The mission showcased India's technological prowess and its ability to undertake complex space missions with precision. It served as a testament to the nation's commitment to space exploration and scientific discovery.

The successful execution of Chandrayaan-3 also reinforced international collaboration in space exploration. It underscored the importance of sharing knowledge, expertise, and resources to advance our understanding of the cosmos. India's space agency, ISRO, welcomed collaboration with other nations, furthering the spirit of cooperation in space exploration.

Chandrayaan-3 resonated with students, scientists, and space enthusiasts worldwide. Its success was a testament to the dedication of the scientists and engineers who worked tirelessly behind the scenes. It ignited a spark of curiosity in young minds, inspiring the next generation to pursue careers in science, technology, engineering, and mathematics (STEM).

Conclusion

As Chandrayaan-3 continued its journey across the lunar surface, transmitting valuable data back to Earth, it reminded us of the indomitable human spirit of exploration. It was a mission fueled by curiosity, driven by science, and empowered by technology. India's foray into lunar exploration with Chandrayaan-3 has not only expanded our understanding of the Moon but has also set the stage for future endeavours in space exploration.

In the grand tradition of lunar exploration, Chandrayaan-3 has left an indelible mark on the annals of space history. It has inspired countless individuals to dream beyond boundaries, to reach for the stars, and to continue pushing the boundaries of human knowledge. In the years to come, as we gaze at the Moon, we will remember Chandrayaan-3 as a shining example of human ingenuity and the unquenchable thirst for discovery. It is a reminder that, in the pursuit of the unknown, we can achieve the extraordinary and unlock the secrets of the universe, one mission at a time.

Sneha Khandade (BTech EP, 2nd year)

ROLE OF ATOMIC PHYSICS IN ASTROPHYSICS

Atomic physics and astrophysics could not be further apart. Yet there is no astrophysics without atomic physics. Read on to find out how both these fields of physics engage in an extraordinary dance to support our understanding of the cosmos.

Atomic physics focuses on studying the structure of an atom, its nucleus and its electrons, and its behaviour and interactions under conditions like electric and magnetic fields. On the other hand, astrophysics deals with the study of the physical phenomena of astronomical bodies. "Atomic astrophysics" – as much of an oxymoron as it sounds, the concepts of atomic physics are extensively employed in the field of astrophysics.

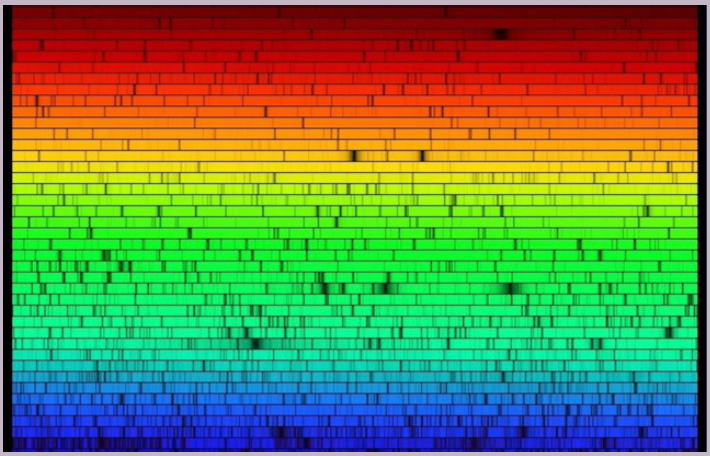
The most common applications are in astronomical observations, wherein atom-photon interactions and concepts of optics and electromagnetic waves are used to record data, as electromagnetic waves are considered major carriers of information in the field of astronomy (the other being gravitational waves). Another application of atomic physics in the domain of astrophysics is in the form of plasma physics, which includes study of hot, dense, and highly energetic regions of the universe, where it is necessary to understand the behaviour of ionized gases.

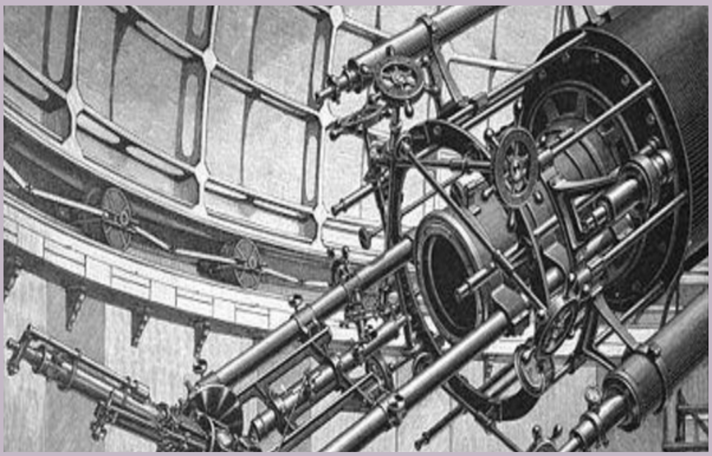
1. ASTROPHYSICAL SPECTROSCOPY

Spectroscopy is the study of the interaction of electromagnetic radiation with matter.

As a result of this interaction, the electromagnetic spectrum carries information about that matter, namely, its temperature, density, elemental and molecular composition, magnetic behaviour, velocity, mass, and size, among other things. The techniques of spectroscopy are used in astronomy to measure the electromagnetic spectrum emitted from stars, galaxies, active galactic nuclei and many more astronomical bodies in the universe.

In very basic terms, how spectroscopy works is that the radiation emitted by an astronomical body passes through and interacts with matter before reaching our observatories. Every element on the periodic table has a unique frequency and wavelength of photon it absorbs and emits (the corresponding spectral lines are called absorption and emission lines, respectively). The consistent presence of a particular element in the path of radiation causes its spectra to have a line at a very specific position due to that element. There are similar lines on different positions due to different elements. We can infer from the spectra the composition of matter and, consequently, its other properties. Shifts in the spectral pattern tell us about the motion of the body away from us (redshift) or towards us (blueshift) and its velocity.





The image on the left shows a high-resolution absorption spectrum of the sun, using the Fourier Transform Spectrometer at the National Solar Observatory in Kitt Peak, Arizona (Credits: NASA); the image on the right shows the Star Spectroscope of the Lick Observatory in 1898 (Credits: Wikipedia).

1.1 PHOTOMETRY

Photometry is a concept closely related to spectroscopy; it involves measurement and calibration of brightness in certain wavelengths or bands, i.e., it studies total emission in a specific region of the electromagnetic spectrum, as opposed to spectroscopy, which studies the energy emitted in a continuum (emission over a broad range of wavelengths like blackbody emission, Bremsstrahlung emission etc.) and lines (emission due to quantum mechanical transitions between discrete energy levels). In simple terms, photometry measures spectral energy with low resolution; spectroscopy determines the division of energy with high resolution at specific wavelengths associated with atomic and molecular transitions.

1.2 RADIATIVE PROCESSES

Radiative processes within astrophysical plasma (constituting electrons, protons, and ionized elements in traces) determine the formation of the radiation spectrum and hence, are fundamentally important in the field of astronomy. Intrinsically it depends on atom-photon interactions, but various external factors like temperature, pressure, abundance of elements, magnetic field etc., also come into play.

A charged particle when accelerated, gives out radiation. The power emitted is given by Larmor's formula,

$$P = a^2 \left(\frac{2e^2}{3c^3} \right)$$

hence electrons are an efficient source of radiation.

There are various ways to accelerate an electron. Under the electric field of a proton, if the electron is bound, it results in radiative transitions:

$$h\nu = hcR_H z^2 \left[\left(\frac{1}{n_1}\right)^2 - \left(\frac{1}{n_2}\right)^2 \right]$$

and if the electron is unbound, it results in Bremsstrahlung radiation:

$$\epsilon_\nu = n_e n_p T^{-1/2} \exp\left(-\frac{h\nu}{kT_e}\right) g_{ff}(T_e, \nu)$$

If the electron is accelerated due to an external magnetic field in non-relativistic speeds, it is known as a cyclotron:

$$h\nu = \left(\frac{1}{2\pi}\right)\left(\frac{eB}{m_e c}\right)$$

and in relativistic speeds, it is known as a synchrotron h =212eBmec.

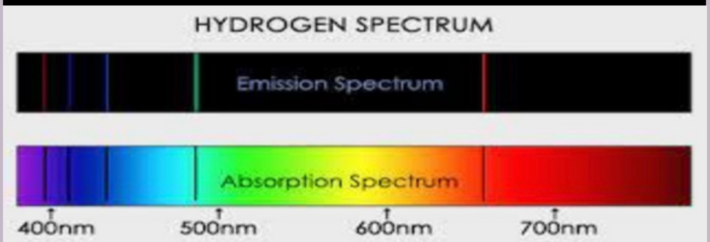
$$h\nu = \gamma^2 \left(\frac{1}{2\pi}\right)\left(\frac{eB}{m_e c}\right)$$

Identifying the radiative process which led to the spectrum formation reveals a lot about the environment of the plasma. For example, the wavelength of radiative transitions gives us information about the elements present in the source. Another example is that Bremsstrahlung radiation helps us identify the amount of dark matter around galaxies, by calculating the difference between the energy due to the mass of the galaxy itself and the energy showing up in its Bremsstrahlung X radiation.

1.3 EMISSION VS ABSORPTION

As described above, an accelerated charged particle emits radiation. Absorption occurs when radiated energy is absorbed by an atom, causing a black band at the wavelength of energy absorbed. For every emission process, e + X → e + X + photon, where X is a proton or a magnetic field, there is a corresponding absorption process, e + X + photon → e + X.

The image below shows the emission and absorption spectrum of a hydrogen atom. (Credits: Physics Stack Exchange).

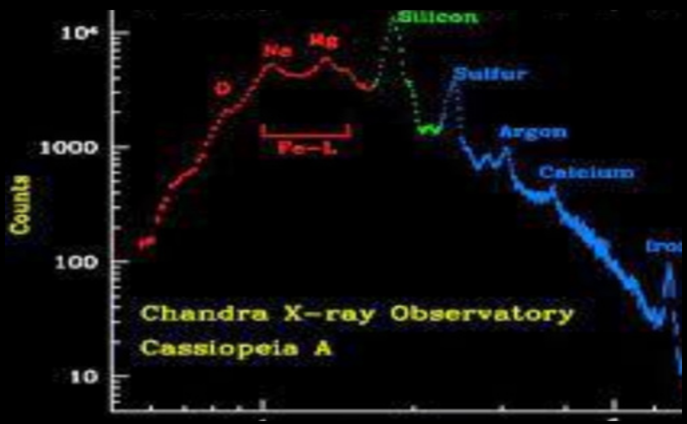


In equilibrium, e + X ↔ e + X + photon, the photon has the same temperature as the electron, and the resultant spectrum is a blackbody radiation. This spectrum helps us find the temperature of the source.

1.4 INSTRUMENTS AND OBSERVATORIES USED IN ASTROPHYSICAL SPECTROSCOPY

A few of the observatories which have been working for years, helping to gather astronomical data and measure electromagnetic spectra of radiative sources include : International Ultraviolet Explorer (IUE);

Hubble Space Telescope (HST); Extreme Ultraviolet Explorer (EUVE); Infrared Space Observatory (ISO); Hopkins Ultraviolet Telescope (HUT); Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph – Shuttle Pallet Satellite (ORFEUS-SPAS); Solar and Heliospheric Observatory (SOHO); Far Ultraviolet Spectrograph Explorer (FUSE); Chandra X-Ray Observatory; XMM-Newton; Galaxy Evolution Explorer (GALEX); Constellation-X, now the International X-ray Observatory (IXO); Suzaku, a reflight of ASTRO-E; and ASTRO-H. The image below shows the Chandra spectrum of the star Cassiopeia A, illustrating characteristic X-ray peaks (Credits: ResearchGate)



2. PHOTOIONIZATION

Most of the observable matter in the universe is ionized plasma. The two main sources of ionization are collisional ionisation (the kinetic energy of a free electron is used to release an electron trapped in the electric field of a nucleus) and photoionization.

The process of photoionization is the interaction of electromagnetic radiation with matter resulting in the dissociation of that matter into electrically charged particles, or ions. When photons travel through stellar atmospheres and nebulae, they are likely to interact with matter and,, therefore with ions. This makes the study of photoionization of atoms, molecules, and their positive ions very important for astrophysicists, helping them to interpret stellar data (using spectroscopy). Photoionization describes the chemical evolution of the universe.

In photoionization, a photon incident on an atom X imparts sufficient energy to an electron for it to be ejected from the atom, leaving it with one additional charge, i.e., X + hv → X+ + e (ϵ). The ejected free electron, often termed as photoelectron, is said to be in the continuum with positive energy, ϵ = (mv2)/2, which is equal to the difference between the photon energy and the ionization potential, i.e., hv − EIP = (mv2)/2.

The image above shows galaxy UGC 11185 from the Hubble Space Telescope (Credits: NASA, ESA). The process of photoionization allows us to see the glowing, green nebulae present in the galaxy.

Conclusion

Recently, we celebrated the huge accomplishment of Chandrayaan-3 successfully landing on the south pole of the moon. Its rover payloads incorporate Alpha Particle X-ray Spectrometer (APXS) and Laser Induced Breakdown Spectroscopy (LIBS), both of which would be used to study the elemental composition of the lunar surface, using methods of spectroscopy and atomic physics. Similar instruments have also been used in Mars rovers such as Opportunity, Spirit and Curiosity for analysing the Martian soils. We see that the concepts of atomic physics are consistently being utilized in astrophysical research, and will continue to be, in the time to come.

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