SMALL PROTABLE X-RAY GENERATOR FOR RADIOGRAPHY

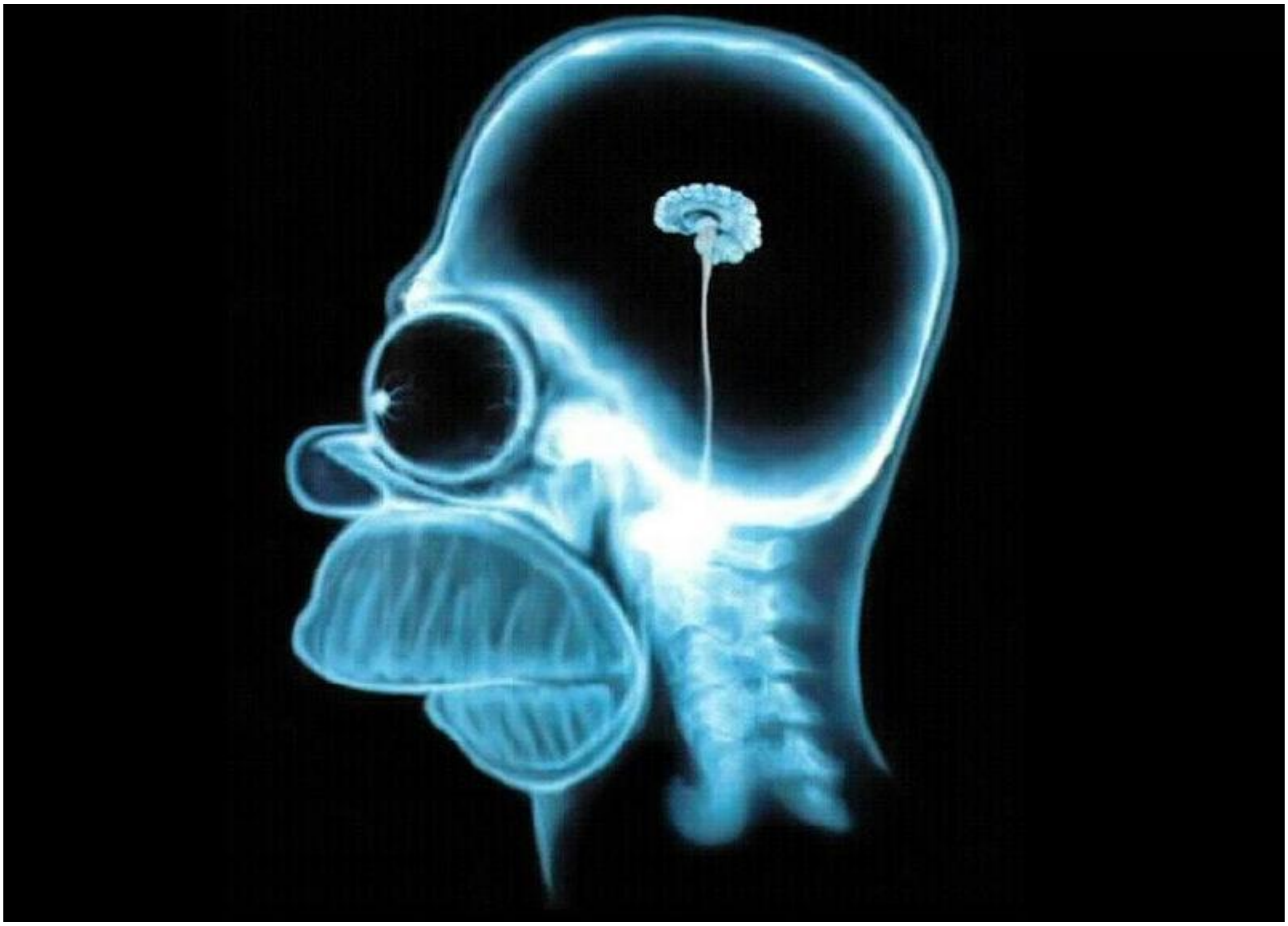

Figure 1 the X-ray radiography of a well known cartoon character, Homer Simpson.

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PASS WITH MERIT

RESEARCH PAPER
BASED ON
PATHOLOGY LECTURES
AT MEDLINK 2010

Abstract

The aim of this project is to suggest a theoretical design of an x-ray generator based on recent research of Nanotechnology. In this project, we will give an overview of Nanotechnology and how nanotechnology is linked to medicine, as well as the ethics of Nanotechnology and our hypothesis on the future direction of Nanotechnology development. Illustrating the importance of x-ray radiography, we are able to show the problem with a modern x-ray generator. Using nanomaterials of recent research, like Bucky paper, we came up with a possible design and mechanism of a small portable x-ray generator. Although this design is theoretical, we can still conclude that it is workable if we are able to test our design and make modification to develop it. We can foreseen the possibility of this technology to be made more common to the general public, once the price of nanomaterials decrease through large industrial production. In addition, we hypothesis the development of a small and portable computerise tomography (CT scan) machine through the design of our x-ray tube.

Introduction

Brief overview on Nanotechnology

We could imagine a world where everything is artificially made by humans using Nanotechnology. This fanciful world will achieve the many "impossible" or "unsolvable" or even "unimaginable". The term Nanotechnology was first describe by Richard Feynman in the talk "There's Plenty of Room at the Bottom" on 1959. During his talk, he described a theoretical process that could manipulate individual atoms and molecules, by using a set of precise tools to build and operate on another proportionally smaller set. 15 years afterwards, Professor Norio Taniguchi put this term into a paper with a definition: "Nanotechnology mainly consists of the processing of, separation, consolidation and deformation of materials by one atom or by one molecule." As a result, Nanotechnology means working at the molecular level.

Arguably the most iconic discovery of Nanotechnology is the buckminsterfullerene, C_{60}, or commonly known as Bucky ball. In which Bucky ball is discovered by five researchers including Smalley in 1985. Bucky ball is the third form of carbon. It is a spherical molecule consists of 20 hexagons and 12 pentagons which give the shape of a football (Figure 2). It is very special because it is hollow in the centre, where this unique structure allows the ability to put another molecule into a molecule. Apart from Bucky ball, carbon nanotubes and Bucky paper are two key materials that are very popular in the field of Nanotechnology. Carbon nanotubes are allotrope of carbon with a cylindrical nano-structure, which was discovered in a few years after Bucky ball. Bucky paper is a macroscopic aggregate of carbon nanotubes, which was invented by Ben Wang 15 years later. All three nanomaterials have amazing properties that does not exist in any other materials, this allows machine to be made smaller and faster. Not only that, it opens up new medical treatment.

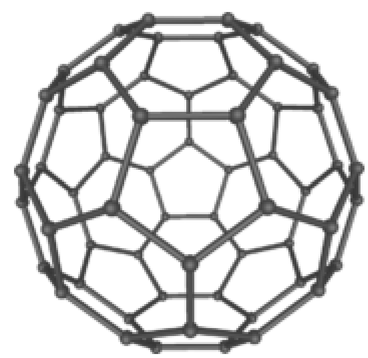


Figure 2 Buckminsterfullerene

Using Nanotechnology, we could create new drugs and new treatments. For instant, new researches shows that nano-gold particles could be use to kill cancer cells when combined with radiotherapy. As nanotechnology is working at the molecular level, we could work ways to combat illnesses on a molecular level. Taking cancer as an example, we could use the hollow shape of Bucky ball to put cancer drugs inside. As a result, we can protect the drug until it is released to the tumour. Not only, could we use Nanotechnology to treat illnesses, but to understand disease as well. If we are able to understand bacteria and virus at a molecular level, we could produce treatment that could target the specific problem more easily.

Why X-ray?

The ability to know what happened underneath our skins is very important, as many potentially lethal decease and illnesses are undetectable with our naked eye. Even with careful clinical examination, a radiography scan is always useful for evidence or to detect any other underlying illnesses. Most importantly, the scan will provide the location of the problem. In addition, it is often true that prevention is better than cure, both in economically and for the welfare of the patient. In fact, radiography is one of the main ways for cancer detection, because early cancer stages have very little signs. Using cancer treatment as an example, billions of pounds could be saved on cancer drugs if we detect the cancer earlier, because surgery is cheaper than chemotherapy and radiotherapy. In a patient's point of view, having a one-off surgery is considered to be less painful than months or years of chemotherapy and radiotherapy. In addition, especially with chemotherapy, the drugs could potentially cause a lot of undesired side effects that would traumatise the patient both psychologically and physically. As a result, radiography is recommended in regular body check, as prevention is better than cure.

Figure 3 an x-ray generator in a hospital

The machine of an x-ray generator is often very large and bulky, and it needs a large supply of electricity for the machine to work (Figure 3). This becomes a problem in terms of accessibility of taking such scans, as there are only very few of these machine in a hospital to meet the high demand. In fact, it is about 41.5 million per year. Not only patients at home are affected by this problem, soldiers overseas are affected as well. It took on average 89 minutes to get from the battlefield to the army camp hospital for an x-ray scan. Not to mention, an x-ray scan could speed up the surgery as it provides the surgeons with the location for the bone fracture or bullets embedded inside the body. On the other hand, animals are equally affected by this, as it is hard to transport a wounded horse from a far away farm to a veterinary clinic.

Summing up the above problem, medical care is often delayed because of the inaccessibility of an x-ray examination. A solution to the problem would be having a small portable x-ray generator that is easy to control and could be carried to the scene of emergency or one that could be fitted in a small place. This will speed up the time taken from the battlefield to the theatre operation table, thus increase survival rate. In another situation, an x-ray examination could be done on the ambulance from a traffic accident scene to the hospital. And if an x-ray generator is small enough to be fitted in a GP surgery, then more people could be benefited from having an x-ray examination as a regular body check. In a veterinary case, if an x-ray machine is small enough to fit inside the tool bag of a veterinarian, then it will make it easier for veterinarian to diagnose animals in a farm.

Main Discussion

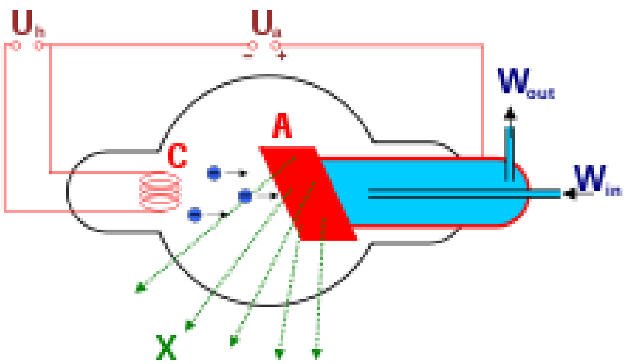


Figure 4 Simplified diagram of a water cooled x-ray tube

An overview of modern x-ray generator

It is important to know how a normal x-ray generator works, before we try to show how to minimize the bulky machine to a "nano" x-ray generator.

This is a simplified version of the x-ray generator (Figure 4) made by Thomas Edison in 1895, and by 1896, the fluoroscope he developed became the standard for medical x-ray examinations. From the diagram, x-rays are produced in an x-ray tube which is a vacuum glass tube. There is a cathode end (C in figure 4) and an anode end (A in figure 4). A water cooling system is linked to the anode as a heat sink. The cathode is a coiled wire for a charge build up. In simple words, x-rays are generated when the electrons accelerate from the cathode hit the target at the anode, where the target is angled to give the maximum x-ray to one direction. As a result, a high current is needed to accelerate the particles and create a high temperature. This shows that the x-ray generator use a lot of electricity and is not energy efficient. Moreover, water is used to reduce the heat at the cathode, hence more energy is needed to power a water plumping system, or many water resources would be wasted. Since it need a high amount of electricity, one could imagine the x-ray generator needs a fairly high up-keeping cost.

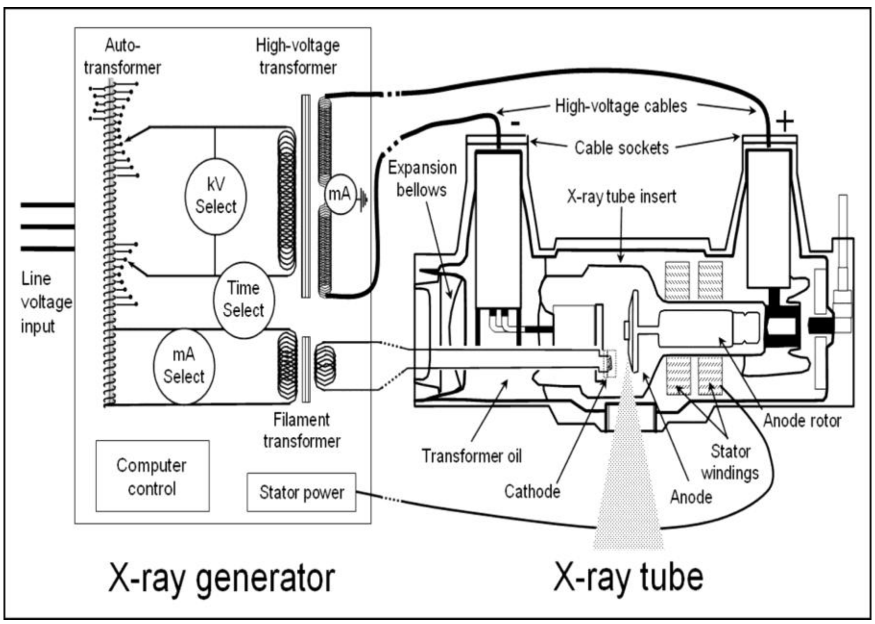


Figure 5 Diagram of a modern x-ray generator.

This is a diagram of the modern x-ray generator (Figure 5). Apart from the rotating cathode and the computer control, it is very similar to the one Thomas Edison (1895) made. The computer control box illustrates how a radiologist can alter the voltage (kV in figure 5), the current (mA in figure 5) and the exposure duration (Time in figure 5) to control the amount of x-ray produced. The circuit is parallel circuit, the bottom one provide the source of electrons (cathode), while the other circuit maintain a close circuit when the electrons jump from one end to another. The cathode is not stationary, as the rotating movement will prevent the building up of the heat energy on a particular point, because if the electron bombardment area is small, the target area will melt.

X-ray generator with nanomaterials

The new design is based on the current x-ray generator, so the main principle is the same. However, there are 4 main replacements of nanomaterial and some fine adjustments in the structure. This allows us to minimise the machine to a very small size and a lighter weight, but still able to achieve the same effect on a medical purpose.

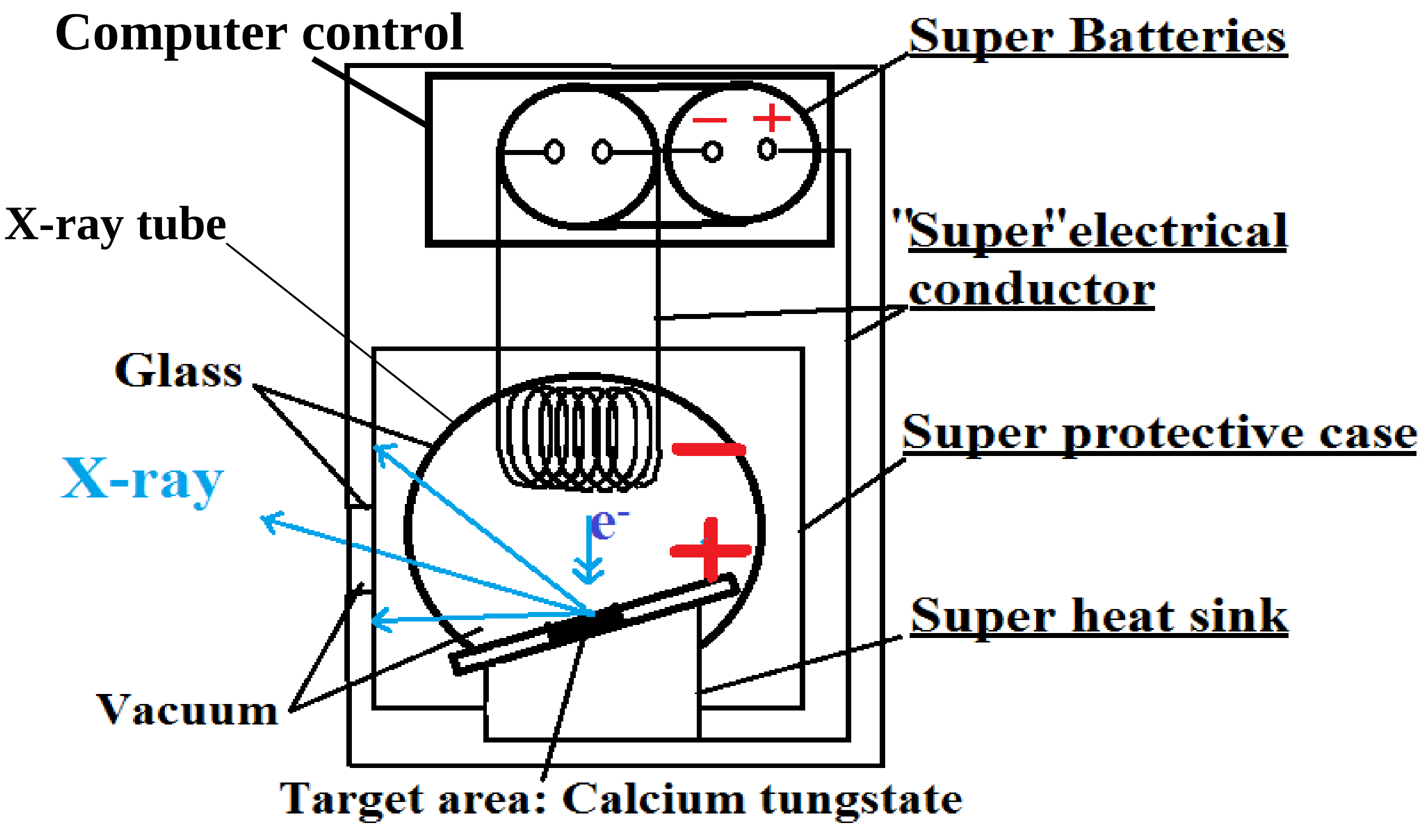


Figure 5 A 2D graphical layout of the main component of our x-ray generator.

Overview

The size ratios of different parts of the components on the above diagram are not proportional to the real size of the machine. The x-ray tube is magnified to show to the mechanism of the x-ray tube. If this design is produced to their real ratio, the battery is much bigger than the x-ray tube. In fact, it will be the biggest component of this machine.

As can be seen on the diagram (figure 5), the machine mainly consist of two parts, the x-ray tube and the computer control box with the batteries. The circuit that power the x-ray tube is a parallel circuit, where one circuit is responsible to the build up of electrons on the cathode, whilst the other circuit is there to remain a close circuit once the electrons jumped to the anode. A separate circuit is attached to the battery to draw electricity to power the computer control box, which is linked to a LCD display (not shown on figure 5).

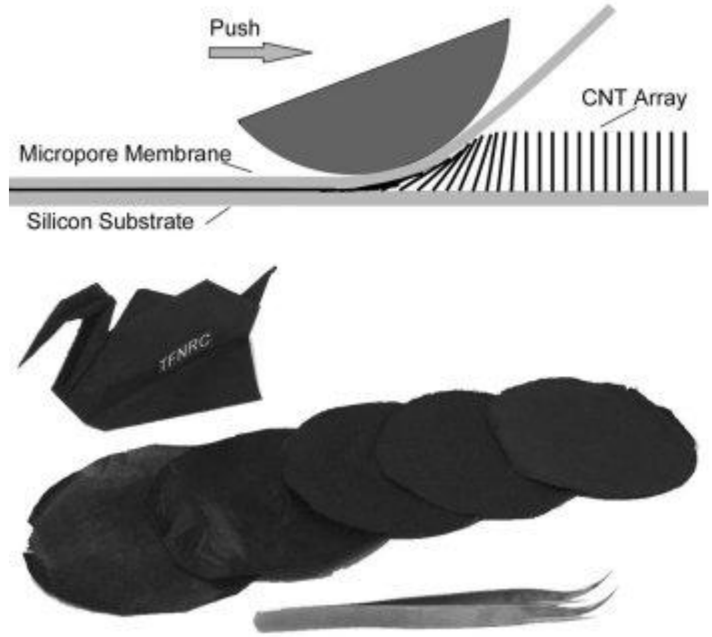
The x-ray tube is a glass with vacuum inside, as the electrons might collide with the particles in air which will slow down the electrons. Inside the tube, the cathode is the part where electrons are accelerated to hit the angled target on anode. We use a very heavy compound (calcium tungstate) that was used in Thomas Edison's work (1895). The anode is linked to a heat sink, which will reduce the heat from the electron bombardment. Around the x-ray tube is a protective case, where it will absorb the x-rays that did not go through the glass window.

Replacement of different components

The following is a brief insight on the nanomaterials we used on our design.

Super Batteries

Recent research shows that carbon nanotube could be successfully synthesized as “super batteries”. It was done by simply adding the carbon black powder to the starting solution of SWNT/Triton X-100 standard dispersion, followed by the filtration technique via positive pressure. Using Bucky paper (Single-Walled Carbon Nanotube/Carbon Black Composite Paper) (figure 6), it gives this new battery cell a very good cyclability (ability to cycle) and electrical conductivity comparing to any other small-sized batteries. Meanwhile, the weight of the whole cell remains low because it only weights only 15 percent as much as copper. Not to mention, it is 500 times stronger than steel, and it is a very good electrical conductor and thermal conductor.



We use Bucky paper as the battery because of its strength, its lightness and its electrical conductivity. A modern x-ray tube needs about 30 to 150 kV, although using carbon nanotube as the electron accelerator require less voltage, one could assume it still consume a high amount of electricity. As a result, for an x-ray generator to be portable, either it need a wireless power cable or a very strong battery, the former is not yet achievable with high voltage, whilst the latter is achievable with Bucky paper.

“Super” electrical conductor

We chose to use carbon nanotube as our electrical conductor is because of their great electrical conductivity. Carbon nanotubes (figure 7) are formed by C_{60} Bucky balls, where they are ultra-tiny cylinder which is 50,000 times thinner than a human hair.

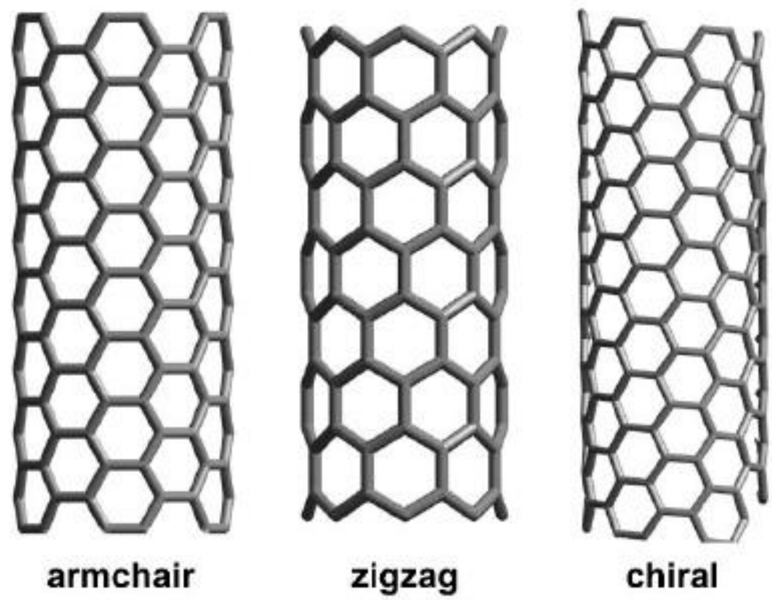


Figure 7 theses are all carbon nanotubes, but of different forms.

The advantage of using nanotube wire is that it has a higher maximum current densities and very little power dissipation, also by comparing with other current wire material. In a point, the electric current density can be up to 1000 times greater than that of metals such as copper. The property of this material mimics closely a virtual superconductive wire, as it has a near zero electrical resistance value. Another reason is that recent research shows that “nanotubes behave like tiny electron guns and operate at few volts, rather than the thousands required for conventional x-ray sources. CNTs also have other unique properties that include extremely high mechanical strength, high thermal conductivity, and excellent chemical and thermal stability.” They are quoted from the paper by Otto Zhou (2003), and most of our understandings of the electrical behaviour of carbon nanotube are indebted to his work.

Super protective case

Using strongest carbon nanotube (zigzag in figure 7) composed Bucky paper provides a safe case for the inner system of the new x-ray generator, because as mention before, Bucky paper is 10 times lighter but 500 times stronger than steel. In fact, the US government is trying to make fighter jets from Bucky paper. The stiffest Bucky paper's Young modulus value can be up to 5000GPa which is 100 times of that of aluminium. As it only weights 1/10 of steel while 500 times stronger, it therefore forms an excellent protection from damaging the x-ray tube. It can also absorb x-rays, so it prevents x-rays leakage in either short-term or long-term uses.

Super heat sink

Fulleride superconductor is used to replace the original heat sink. It gives significant improvement in functioning, since recent research shows it could reduce the heat using its remarkable structure. This material is found in the research "Fulleride Superconductors are Three-Dimensional Members of the High-T_c Family" by Kosmas Prassides and Matthew J. Rosseinsky.

Fulleride superconductors are high-temperature superconductors where alkali-metal atoms are intercalated into C_{60} molecules which still show superconductivity at temperatures of up to 38 K. This property thus gives merit to electrical conductivity as well. Since the strength of nuclear bonds of atoms in Bucky paper is 2 times as strong as that in diamond, the melting point is incredibly high. Therefore it can withstand the high temperature without melting. In Addition, the thermal conductivity of this material can be up to 3500 W/(mK) which is about 9 times of that of copper, this makes it a perfect material composing with fulleride to dissipate heat out from the system efficiently to prevent overheating and also to increase electrical conductivity. Base on the research of Otto Zhou (2003), we do not think a heat sink is needed, but on the caution of safety, we added a heat sink on anode.

Nanotechnology and medicine

Nanotechnology leads us on the path to a "nanoscale understanding" of science, as in basic terms, Nanotechnology means the study in a molecular level. Before the start of the development in nanotechnology, many biological aspects remained dormant and unknown, and many findings or invention of new treatments are purely accidents. But with continuously researching in nanoscale aspects, more advantages are discovered in human's live, particularly in medicine.

Since the hit on Nanotechnology arises, "the molecular level" started to play a significant role. Further and deeper observations could be done in many kinds of biological livings, due to the development of the atomic force microscope (AFM) and the Scanning Tunnelling Microscope (STM). They are two very import developments that allow one to see the structures at the nanoscale, which were developed from the work of Marvin Minsky (1961). For example, many different kinds of bacteria are investigated at the molecular level, and we were able to see how the toxin molecules are produced by them. As a result, one can imagine by knowing the structure of that toxin, in a not too distant future, we could build the exact inhibitor with the exact complementary shape and charge.

One inspiring thought about "learning from nature" stains crucial colours in medicine. For instance, examining and observing how cells are repaired raises scientists' awareness on the importance of our natural recovery. Especially with brain cells, as one, we cannot replace someone's brain, and two, we cannot replace the cells in the brain. As a result, scientists hold their hopes on Nanotechnology to do the job. By studying how our cells are naturally repaired, we could build a biological robot (enzymes) to do it. If this is really developed, it will help build up better and more comfortable treatment for patients, so they do not have to suffer from huge surgeries. More than that, the idea of natural recovery could inspire more environment friendly technology development, which could make people rethink the importance of nature resources.

On the other hand, nanoscale observation in human part nudges ongoing development of medical immunity. Tissue cells, DNA, cancer cells etc. are being observed by doctors and scientists. In an attempt to matches the finding in disease-causing organisms. If we know the structure of the receptors of the disease causing antigens, we could build any type of antibodies molecule by molecule. And therefore, the medical achievement can accelerated beyond our imaginations. Potentially countless more Nanotechnologically developed products will be invented. From the new designed of x-ray generator in previous section to unbelievable nano-robots that can cure any disease. But back to the basic, a nanoscale of understanding of science is needed.

Ethical issue

A world full of Nanotechnology would be like living in 'Star Track' or other science fictions, to be more precise, a world when everything is made or build up molecule by molecule using nanomaterial with unbelievable properties. This fantasy world seems to be a perfect place to live in, and this fantasy does not seem to be a far distant future, as we are already able to do experiment at a nanoscale.

However, having the ability to do all these different experiments and researches does not mean we are fully understood about this cutting-edge technology. As mention above, the term "Nanotechnology" only started 52 years ago, so it is a very new technology and we are still pitching in the dark on this subject. As we cannot hypothesis how each research or development will turn out, it could go into two extreme categories, either an innovation that would benefit us or destroy us. In addition, there is not a well regulated system in law on the field of nanotechnology research and development.

The main ethical concern surrounding Nanotechnology is that the ability to manufacture at an atomic level is too powerful for a nation or for human beings. Some argue that having this "God-like" power is simply unethical, while others suggest that if this technology is misused, then the consequence of that will be catastrophic. Secondly, since almost all of the Nanotechnology research is funded by the government, the research agenda is naturally controlled by the government. To be more precise, the government might want the researches to be focus on developing new tanks and weapons, so researches on medicine might not get as much funding. Thirdly, Nanotechnology will potentially eliminate other ethical issues; for example, building meat by molecules instead of slaughtering animals, or building cells by parts instead of using existing cells from another animal or human (e.g. stems cells). This could be beneficial, but also controversial that anything produced would be unnatural.

Conclusion

Since our design is only a theoretical design, hence the design might not work this way in reality, but we still came up with the following ideas to modify it to a workable machine. Firstly, we would test if x-ray could be produced this way, so we would build only the x-ray tube and its protective case. If x-rays are produced successfully, we would test if any x-rays are leaked from the case. If so, we would increase the thickness or ultimately change the case to the original material (lead). Secondly, we would alter the angle of the target to give its maximum x-ray at a given voltage. Having done so, we test the maximum amount of x-ray the protective case can withstand. This is helpful to set the voltage and current limit that one can change. Thirdly, we would build our own “super battery” that could meet our ideal performance, which is once fully recharged; it could emit x-rays for 48 hours simultaneously, and have a week stand-by. And finally, we would work with IT technician to work out the easiest programme to control the computer device on the x-ray generator.

An important detail of x-ray radiography is not mentioned is that the x-ray generator work just like a camera, as it needs a film, either a digital one or a photographic one. As a result, we suggest a development for our design is to include a large x-ray detector that could roll up like a thin mat. This detector would also have a wire which would be linked to the LCD display to show “real-time” image, which would work like a fluoroscope.

Furthermore, it has not escaped our notice that the design of our x-ray tube suggests a possible mechanism and design for a small portable x-ray computerised tomography machine, which would simply look like a hula loop with a wire attached to a laptop.

Our hypothesis on the future of Nanotechnology

Taking everything into consideration, Nanotechnology will be the way forward on science. In medicine, we think more research will be done to learn from the nature, if we could produce artificial antibodies like our immune system, then there is nothing we could not combat. The advance on Nanotechnology could increase the likelihood of personal medicine. On the other hand, nanomaterials will be more and more popular, as it is energy efficient, thus environmental friendly as well.

A gram of Bucky paper cost about $2000 USD in 2009. Nonetheless, we believed that through industrialisation of mass production of nanomaterials, the price could be dropped to the price of a piece of normal paper. Apart from that, Nanotechnology research cost a lot of money, whilst the government subsidise a lot, it might still be not enough for the researchers to get the best resources. Regardless of the cost, there are many opposing it because of ethical issues. Nevertheless, we hold very positive views regarding the future of Nanotechnology.

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