Nobel Laureate for Physics Prof. Sheldon L. Glashow's keynote speech and dialogue "How basic science drives technological progress" on Wednesday, February 8, 2017, at BINUS University in Jakarta

Let me first thank the International Peace Foundation and BINUS University for making this trip possible for me and my wife to come to this glorious and fascinating country, Indonesia, where we have never been before.

This morning when I was at BINUS school one of the younger students asked me what is the relationship between science and peace. Perhaps I didn't give the right answer at that time, but I have been thinking about this question, and it comes to mind that science is the most international of all disciplines. Countries that are at war with each other, that hate one another, still cooperate scientifically. Remember during the time of conflict between the West and the Soviet Union there was great fear in the world about a nuclear war, but during all those years scientists in the Soviet Union and the United States were in communication with each other, were visiting each other when possible and were collaborating on scientific problems. There are over a hundred countries that cooperate with one another at CERN, the European laboratory for particle physics. Science is truly international, and we get along with everybody in science.

I will be talking today on “"How basic science drives technological progress” and vice versa. We will also speak of the converse, of how discoveries in technology can lead to progress in basic science.

Discoveries made in science can be intentional or accidental. Some technological advantages, such as those of X-ray and penicillin, arose from research that was unplanned and not directed toward any specific goal, let alone a useful goal. These discoveries were unexpected and stumbled upon by accident. Other discoveries, like streptomycin or nuclear weapons, resulted from carefully planned and specifically targeted research. Both are valid forms of scientific endeavor, and the history of science shows that both methods are essential, and I say this because it must be born in mind by aspiring scientists and by governments, academies and industrial agencies that seek to foster scientific and technological progress: There are two roads to discovery.

Emmanuel Kant taught us the so called “scientific method”, and let me compare the scientific method with serendipity. The word serendipity comes from a story called the 3 princess of Serendip, which was written hundreds of years ago.

Some scientists focus on well defined goals, first they lay careful plans and then they look – they follow the scientific method, and I call this the Kantian approach, following Emmanuel Kant. Others have a lot more fun, they look and listen to nature with an open mind, and sometimes they discover amazing and unexpected things. I call this the serendipitous approach, like Columbus' discovery of America, when he set out to find China, but discovered America instead, and unlike Magellan, who formulated a successful plan to sail around the world, and his boat did just that although he himself lost his live in the process.

The two approaches often mix, many Kantian efforts yield surprising discoveries. TNT was synthesized in 1863 and used as a yellow dye for 28 years until his value as an explosive was discovered. Thalidomide was originally used as a sedative for pregnant woman in the 1950ies in Europe, and it lead to a medical disaster, however much later Thalidomide is used again as a very effective drug for treating certain kinds of cancer and leprosy.

Basic science can proceed either by intentional means, Kantian means, or through serendipitous means, but there is a second dichotomy. Basic research can be pure, solely driven by curiosity or applied and dedicated to some specific, societal, commercial or military need. Some examples are the discovery of the Higgs Boson at CERN in 2012, which was Kantian, and so was the remarkable discovery of gravitational waves in 2015. Those are examples of pure science, the Higgs Boson is not useful, the gravitation of radiation is not very useful, and both discoveries were very Kantian, and following the scientific method.

What about pure and accidental discoveries?

In 1932, the year I was born, Positrons were discovered quite by accident. In 1985 Fullerenes or Buckyballs were discovered, these are molecules consisting of 60 or so carbon atoms arranged in the form of a football, another serendipitous discovery in pure science.

Or you can have applied science, which can proceed in a Kantian method – for example a Japanese scientist, who dedicated plant research, discovered blue LED which made possible a revolution in lightning which we experience today, or in China, a Chinese person received the first Nobel Prize in the sciences recently through the discovery of a medicine emerging originally out of traditional Chinese medicine for malaria.

The final category is applied and serendipitous research, such as the discovery of graphene and the discovery of the giant magnetoresistance effect, which you've probably never heard of, but that was the discovery that enabled all of a sudden disc-drives in your computers to have gigawatt memories. There was a tremendous jump in the capabilities of laptop computers due to this discovery.

Chemists make lots of accidental discoveries, discoveries that were all applied and serendipitous and all found through people who were trying to make money, but the people didn't discover what they thought they wanted to discover.

"Chance only favors the prepared mind", said Pasteur, and Terence said: "You must by skill make good of what has fallen by chance."

Examples for this are dyes, many of which are still in use, like Prussian Blue, discovered in 1704, or Mauve, which was discovered by an 18 year old kid named William Henry Perkin, who wanted to become a chemist. An older German scientist recommended him to try to synthesize quinine, which later would become a very important drug for treating malaria. So this kid tried by the destructive distillation of wood to create the beautiful white crystals of quinine, but of course he couldn't succeed, and quinine would not be synthesized for another hundred year or so by some Americans at Harvard University. Instead when Perkin tried to synthesize the crystals he made a stinking mess from the spilling wood, but he noticed there a certain purple color and subsequently was able to extract a dye from that mess, and that was the first aniline dye which became known as Mauve, which then was worn by the Queen of England and the Empress of France, and he became a very rich man. This accident discovery of the first aniline dye was followed by the accidental discovery of the second aniline dye: magenta. Synthetic indigo was discovered in 1897 when a broken thermometer released mercury which acted as a catalyst that enabled the synthesis.

Similar things happened with artificial sweeter. There are 6 synthetic sweeteners and all of them are commercially used in one place or another, saccharin, cyclamate, aspartane, acesulfane, which is the secret behind Coke Zero; and all of them have been discovered accidentally. Chance only favors the prepared mind. In one case they were looking for a medicine for heart disease, but instead they found an artificial sweetener, and everybody was happy and made lots of money.

I will talk now about the electromagnetic spectrum. Those of you who study science have all learned about electromagnetism. The most conspicuous form of electromagnetic radiation is of course light, and it was Isaac Newton who, in a very systematic way, showed that light can be broken up into the seven primary colors. Incidentally it is interesting to ask why there are seven primary colors. Newton came very close to discovering the wave nature of light, but he didn't believe that light was a wave, he believed that light was a particle. But there were hints of wavelight properties and it seemed to him that there was something musical associated with light, and there were seven colors, because there are seven notes in the diatonic scale.

William Herschel, a famous astronomer became curious about why it is when you go to the beach you feel the warmth of the sun. He knew that sunlight consisted of the seven primary colors that Newton had identified, but which color carried the heat of the sun? The way he did this is, like Newton, he split light up into its seven colors and put thermometers down to see which color got hotter in the sunlight, and he found that the thermometer that was accidentally put to the wrong side of red got hot, and so he accidentally discovered infrared radiation. Whereas his contemporary Johann Ritter, when he heard about the discovery that Herschel made, realized that very likely it had to be something funny at the other side of the electromagnetic spectrum, and thus, in a Kantian fashion, he discovered ultraviolet radiation.

Then we have the accidental discovery of X-rays and the accidental discovery of the cosmic microwaves radiation. We are all creatures of electromagnetism, and everything we see, feel, hear, smell, taste or do has to do with electromagnetism. It's electromagnetism that gives the material properties of matter and their solidity. For the theory of electromagnetism we are indebted to serendipitous discoveries by Galvani, who did some fascinating experiments with frogs. That led to the discovery of the electric battery by Volta, which made possible all kind of practical discoveries. Oersted, who during the course of giving a lecture on physics accidentally discovered that electric currents produce magnetic effects. He wasn't looking for anything like that, but he was the first person to realize that there is an intimate connection between electricity and magnetism.

When you study electromagnetic theory you will hear about Ampere, Biot, Coulomb, Faraday, Franklin, Gauss, Gilbert, Jansky, Maxwell, Ohm, Tesla, Weber and many more; and all of them made major contributions to the theory of electricity and magnetism, but except Tesla they weren't out to make money, but they were out to discover the nature of physics. And all of them got to be a unit, each of them is a unit to measure something. Tesla is a measure of the strength of a magnet, Coulomb is a measure of electric charge, Ampere is a unit of electric current and so on; and that is all they got out of it, eternal fame – not so bad.

Now I would like to talk about the virtues of basic science in the field of medicine, and there are so many of them: X-rays, discovered accidentally, and it didn't take long before it was realized that you could use X-rays to tell whether you had a cavity in your teeth, or during the first World War to find the bullet that had lodged into someones body and remove it. Positrons were discovered accidentally in 1932, today they are the basis for PET scanners - positron electron tomography, which are used throughout the medical profession, and that's interesting because all the scanners that are used, CAT Scanners, PET or MRI scanners, they all resulted from discoveries in pure or basic science. Without the discovery of nuclear magnetism at Harvard in 1950 there could not have been MRI scanners. Without the discovery of radioactive isotopes there could not have been many forms of medical therapy. Without the discovery of the cyclotron there could not have been particle beam therapy. Without lasers we could not have microsurgery, for example on our eyes, which I recently had done. Now I can read without glasses for the first time in my life!

Other examples are penicillin or the structure of the DNA itself, both of which were accidentally discovered and each of these basic discoveries lead to a Nobel Prize.

Basic science in IT. IT is very important today, many of you study information technology, robotics and computer science. There were many example when basic science affected information technology, first through the very Kantian discovery of radio waves which lead to wires transmission, the discovery of holography which you can see now on every credit card to make them more secure, the discovery of transistors lead to the first computer revolution, and the discovery of integrated circuits lead to the second. Today we have been revolutionized by computers with cell phones and tablets taking over the world.

I mentioned the giant magnetoresistance effect which lead to multi gigabyte discs, high temperature conductivity which made possible MRI scanners, the worldwide web which is the basis for today's information age, was devised and deployed by physicists for physicists, but it caught on to other people as well, and by the 1970ies we were starting to use emails as means of communications with one another, and soon afterwards everyone was using it. All of this followed some basic scientific discoveries. Quantum manipulation may lead someday to new kinds of computers called quantum computers.

So it goes, and I could go on forever. The photovoltaic effect, the fact that light can make electricity, was discovered in 1839 by the father of the person who discovered radioactivity, and that lead eventually to solar panels and perhaps to a solution to the energy crisis. The photoelectric effect was first understood by Einstein in 1905 and lead to CCDs (charged Coupled Devices) which are the basis of the cameras we have today in our cell-phones. General relativity made possible GPS, matter waves, discovered in a Frenchman's thesis in 1923 made possible the electron microscope, nuclear fission lead to nuclear power, and nuclear power may save us from global warming and climate change. Bucky-Balls lead to something called photodynamic therapy very recently, and graphene was discovered in 2004, and the discovery was also awarded with a Nobel Prize, but doesn't have any applications that I know of yet.

Sometimes it takes a while before a discovery in basic science leads to a practical device. The giant magnetoresistance effect eventually lead to the development gigabyte hard-drives. It took only 3 years before that happened, and IBM jumped into the game and developed the first gigabyte drive.

From CCDs, charged coupled devices, to the digital camera it took 6 years, transistor to transistor radio took 7 years, matter waves to the electron microscope took 10 years, radio waves to wireless telegraphy took 11 years, fission to nuclear power took 19 years, general relativity to GPS took 78 years, and photovoltaics to solar panels took a full 115 years. Of course there are reasons for that delay. It could be a question of necessity, we didn't develop solar panels until we needed solar panels, or a question of missing technology, you can't simply use general relativity to make GPS unless you had satellites and modern electronics, and so it goes.

Let's talk about isotopes.
Atoms come as isotopes, as you all know, with almost identical chemistry but different masses. Some isotopes are radioactive, and they were first found by Soddy in 1912, and some isotopes are stable. They were first found by J. J. Thomson in 1913, over a hundred years ago. The discovery of the neutron enabled nuclei to be characterized by two integers - now I will give you a quick lesson of nuclear physics from A to Z – there are two numbers you have to understand, one is A, which is the atomic mass unit, the numbers of neutrons and protons in the nucleus, and Z, which is the number of protons in the atomic nucleus. Hydrogen has for example three isotopes. All have Z for 1, ordinary hydrogen has a nucleus which is just a proton, heavy hydrogen, also called deuterium, discovered by Harold Urey in 1932, is a stable isotope with hydrogen A = 2, and Tritium, which was discovered in 1934, is an unstable isotope, it is radioactive, and it has Z = 1 and A = 3. And as you all know, uranium comes in a host of different isotopes some of which can't be used to make bombs, like uranium-238 and some of which, like uranium-235 can be used to make bombs or nuclear power.

Isotopes, soon after their discovery, because in the beginning they were just a curiosity, became very useful. Nuclear fission lead scientists to realize that isotope U-235 could be used to make bombs or to provide a clean and novel source of energy. In 1948 Libby invented the concept of radioactive carbon dating, and that was very important in many, many ways. For example there was a relic which was considered holy by the Catholic church, called the shroud of Turin, it was supposed to be the shroud in which Jesus Christ was wrapped up upon his death, but careful study with carbon dating showed that the shroud of Turin was made in the 15th century and had nothing to do with Jesus Christ. That research was, by the way, in part supported by the Catholic church, which was very open minded of them.

With the help of carbon dating we were also able to prove that the Vikings had preceded Columbus to America, that Columbus was not the first Westerner to get to the Americas.

Isotopes are used for almost everything, in astrophysics, in nuclear reactors, for agriculture, for leak and smoke detection, they are used for art preservation or to search for oil and for paleontology, they are used for practically everything.

As an example of pure science the isotopic analyses of ancient rocks, in particular studying the isotopes or uranium in old rocks, enabled us to determine the age of the earth to be 4.54 billion years, plus or minus 0.04 billion years, and that is better than 1% accuracy. Meanwhile astrophysicists have, by other means, established the age of our universe to an accuracy of 1 %. Can you imagine that? Scientists do miraculous things! It is not a very useful fact that our universe is 12.82 billion years old, but what an incredible discovery that is. Makes you proud to be human!

Now, particle accelerators, you've all heard about the Large Hadron Collider (LHC), this great big accelerator that was used to discover the Higgs Boson and that is being used today to search for more of natures' secrets – a fantastic machine that is doing very useful things – but today, there are up to 30,000 accelerators out there doing various useful things. The first cyclotron in 1930 was 4 inches in size and today the LHC is 5 miles wide. Today they are used for medical therapy, for research and diagnosis, they are used to make the isotopes that do all those things I just mentioned, they are used for ion implantation and to make computer chips, to detect bombs, fusion research – we'd like to solve the problem of nuclear fusion to make clean energy and perhaps someday that will be done, they are used for detecting and measuring semiconductor contaminants and so on, particle accelerators are used for so many different things. So it was important to develop these synchrotrons. The reason to build them was not all the things just mentioned, the reason for the discovery of the synchrotron was to investigate the secrets of nature and nothing more than that.

When people were building these accelerators they had a problem. When you try to make electrons go round and round faster and faster, the electrons radiate light and that costs energy, and therefore to run electron accelerators gets more and more expensive as they get bigger and bigger – that light turned out to be very important. The synchrotron light source has become an expensive and very useful device. Synchrotron light today is no longer a problem, but it is used in all kinds of science, engineering, medicine and industry. There are about 80 of these machines in 20 different countries, one of them in Jordan. Even more powerful "Free Electron Lasers" exist in Hamburg, Germany, or in Stanford in the US, and they represent the 4th generation of these things. At least 5 Nobel Prizes in chemistry were awarded for work done at synchrotron light source. Their applications are too numerous to describe. They are used in neuro-chemistry, nanoscience, pharmacology, cancer therapy, molecular biology and material science, they are used to imaging crystals, ribosomes, proteins and viruses, for the analyses of strains, crack and corrosion, they are used in paleoentomology, biochemistry and archaeology – accelerators are used for almost everything in science, industry and medicine. Originally they were just curious little devices, having to do with the most basic and useless of science.

Number theory, another useless science!
G.H. Hardy was a pure mathematician of the 19th century, and he wrote “There is one science whose very remoteness from ordinary human activities should keep it gentle and clean”, and of course useless.

Tell that to the NSA! Number theory has become essential to modern cryptography and is immensely practical. Cryptography is used by the military for encryption and decryption, it’s used for electronic money for gaming and financial services, it is used to encrypt telephone messages or to sign documents online, email security, speech synthesis, securing data integrity and preservation, cyberwar – which we are engaged in today as American security systems get invaded by the Chinese - security trading, concert hall acoustics, cyber-security, computational biology, online payments, ATMs, bitcoin, error correcting codes and secure data transmission for finance, industry, military, governments and individuals. So, number theory has become useful.

Let me give you some converse examples, how technology drives progress in basic science, the opposite from my original subject.

Steam engines were invented long before they were understood. When engineers were playing around with things they didn’t really understand, they developed the first stem engines, and that lead to the industrial revolution, but they also challenged physicists to develop a science that could explain and improve the operation of the original steam engines of Newcomen and Watt. The science of thermodynamics was inspired and driven by the development of the steam engine.

Spark coils were developed by a German engineer named Ruhmkorff in the 19th century, photography was invented by Daguerre and mercury air pumps were developed by Geissler, and these made possible a number of turn-of-the-century discoveries, like the discovery of radio waves, X-rays, radioactivity, the electron, atomic number, cathode ray tubes, all of those developments were fed by the discoveries made by engineers.

The antenna used by Penzias and Wilson to discover the cosmic background radiation of the universe, something very important to cosmologists and something that made possible the determination of the age of the universe to an accuracy of 1%, that discovery was made possible by a device that was built by ATT for the earliest version of satellite communication. After it was no longer useful for ATT Penzias and Wilson used it to discover the cosmic microwave background radiation that is so important today.

An interesting story having to do with the Cold War back in the days when the Americans and the Russians signed an agreement to not test nuclear weapons in the atmosphere, the Americans didn't trust the Russians and wanted to be sure that they were not secretly testing nuclear weapons – they never did violate that treaty by the way and neither did the Americans – but in order to check up with them the Americans had satellites that were looking for violations of the test-ban agreement, and they saw some very interesting things. It wasn't Russians exploding nuclear weapons, but a signal coming from out of space, it was were called gamma-ray bursts, which were very mysterious things in astrophysics until their nature was finally understood in terms of supernovae.

Supercomputers enable otherwise impossible calculations in both pure and applied science, for example the four color theorem, which has proven that you never need more than four colors to make a map, that very sophisticated theorem, very hard to prove, required a computer; and many other things in science and mathematics that could not have been done without the development of supercomputers. The biggest, most powerful supercomputer today is in China.

Now let me tell you a story about synthetic elements and nuclear fission.
In 1925 there was a lady scientist, Ida Noddack, who claimed to find element number 43

and element number 75, that is what we call today masurium and rhenium. Subsequent work showed that she didn't really discover masurium, so that was not accepted as a discovery while 75, rhenium, was.

Then a few years later in 1934 Enrico Fermi, one of the most famous and gifted of all scientists in my discipline, bombarded uranium with neutrons and claimed that he had produced elements number 93 and 94. He even named them, he called 93 ausonium and 94 hesperium, after old names for Italy. Then Ida Noddack, our woman scientist, wrote a paper called "Über das Element 93", talking about the element 93, and she said that she didn't really think that Fermi discovered those elements or there was no way to be sure because he only noticed something interesting happening, but didn't show the elements. In fact, he had not.

Then element 43, the one Ida Noddack claimed to have discovered, but failed, was synthesized by Segre in 1937, so Noddacks prior claim is still disputed, but the decisive discovery was made in 1937.

In 1938 Fermi wins the Nobel Prize for discovering elements 93 and 94, something he actually had not done. He was informed about winning the prize in October, in November he heard that nuclear fissure had been discovered in Germany, and he realized that he had not found elements 93 and 94, but what he was observing, in fact, was nuclear fission. He made a quick change, and when he received the Nobel Prize in December no one claimed that he discovered said elements. Now usually, if someone wins a big prize like the Nobel Prize for something they didn't do, you would think that's terrible, but it wasn't terrible in Fermi's case, because he did a lot of other things as well, and he, if anyone, deserved a Nobel Prize – even though he got it for something he didn't do.

The story goes on in 1940 when element 93 and 94 were found, called neptunium and plutonium, then in 1944-45 americium, element number 95 was discovered, then curium (96) and promethium (61) were found among fission products of uranium, in 1950 berkelium (97) and californium (98) were synthesized, and so it goes.

Today all chemical elements from Z=1 to Z=118 are observed. Some of them are useful, technetium is a corrosion inhibitor. Plutonium is a nuclear fuel, americium is used in household smoke detectors, curium is used as a power source for spacecraft, and californium is used for oil and gas exploration.

The game continues, although heavier elements tend to be rather useless, because they are terribly very short lived. The game is played by a few countries, Germany, Russia, Japan and the US are continuing this more or less useless game of making bigger and bigger elements in the hope that they will come upon elements which are relatively stable. I don't know if they will find it or not, but I wish them well.

Basic scientific research has enabled most of the technological and medical marvels of modern life, but that is not at all what motivates me or most of us who pursue the disciplines of cosmology and particle physics. Rather, as heirs to nature's splendors, we find it our duty to try — as best as we can — to understand the nature of all things great and small: from the birth, evolution and the fate of the universe to the tiniest building blocks of matter and the rules they obey. These are the things we do.

Thank you very much.

Question:

How can a theoretical physics student develop his career in experimental science when he is located in Indonesia, where it is difficult to do research, because the facilities are not here. I know that you stayed in CERN for several years, and as a theoretical physicist you developed your career there, but this is very difficult to do for a student or young scientist in Indonesia.

Prof. Sheldon L. Glashow:

I don't see your problem, because everything that is done in experimental physics is published, and everything that is published is available on the internet today, so being far away from where the experiment was done should not be any obstacle. There are many other obstacles for doing successful theoretical physics, but access to experimental data is available and open, and that is a miracle of the worldwide web.

Back when I was a student the new research was very hard to acquire, even in America it was very hard to know what other people were doing, unless you received information by mail, and then, suddenly, in the 1970ies email was developed, and now people in all the countries of the world, where they can not afford subscriptions to the journals, can still have access to all of the scientific development. So, being here, far away from CERN, shouldn't be a problem for an aspiring physicist.

Question:

I have read a book about Stephen Hawking in which he mentions a theory that scientists cannot find the link between the electromagnetic force and the weak force, and I was wondering how much research is done about that.

Prof. Sheldon L. Glashow:

Your question has to do with the disparity in between the weak and the magnetic force, and that is completely understood today. The understanding is that there was a unification of the forces at very high energy, which was manifest when the universe was very hot. But when the universe cooled down the spontaneous symmetry breaking that Salam and Weinberg had introduced came into play, and that had the effect of making the intermediary of the weak interaction very heavy while leaving the photon masses. The reason the weak force is weak is because the particle that mediates weak force is very heavy.

We understand the breakdown of the electroweak interaction, and we even think we understand the breakdown of the strong-weak electromagnetic forces from a situation of complete symmetry.

Question:

What would be your suggestion to the situation we have in many countries and also in Indonesia where the governments are not supporting basic science research, but scientists would like to work in this field and to reach out to scientists and the technologies which are more established?

Prof. Sheldon L. Glashow:

That is a political question and so a bit hard for me to answer.
I do not know, for example, if Indonesia is one of the countries that are affiliated in any way with CERN, because if it is, then it is possible for Indonesian students to visit CERN to apply to such positions and to spend some time there.

In the US we have various departments, the National Science Foundation and the Department of Energy, which support basic research in many fields. I don't know if there are comparable agencies in Indonesia, but certainly it is true that traditionally since the 2nd World War there has been a lot of support by the US government for basic research. To some extent that resulted from the success of US military research, which developed the radar for example or weapons, and this is one of the reasons why the government continues to support such endeavors. The same is true for space research, the reason we went to the moon had to do with competition between America and the Soviet Union – would we have gone to the moon if there hadn't been the Cold War? I don't think so.

Question:

Is nuclear physics important to be pursued, and what do you think about nuclear as part of the science – is it an opportunity or is it a threat?

Prof. Sheldon L. Glashow:

Many questions in basic science have to do with nuclear physics, so universities such as MIT have active programs in nuclear research.

Is nuclear energy important? Yes, nuclear energy is of paramount importance to the survival of human civilization on earth. Now this brings us back to the question of global warming and climate change. It is certainly true that this country as well as my country or China are burning fossil fuels and destroying forests and are leading to increased emissions of carbon dioxide through various different methods. The carbon dioxide content in the atmosphere has been steadily increasing over the past 75 years, it has increased from 350 parts per million to 405 parts per million, as a consequence the temperature of the earth has increased by about a half Celsius degree, and if it goes another half Celsius degree we are bound to have a lot of problems like flooding, decease or starvation. When water melts in the mountains then the great Asian rivers will not be as they are today, and the food catastrophes throughout India and China which will certainly lead to armed conflict. There will be flooding in Bangladesh, which will be permanently flooded, and hundreds of millions of people will be driven from their homes into nearby India, and they will not be happy to accept tens of millions of migrants.

Or why are so many Iraqi trying to enter Europe or America? Well, partly it's the war, but it's also the change in climate and the quality of agriculture in the Middle East which declined from what it was due to climate change. This will get worse and worse if we continue to burn carbon dioxide. The clear solution, in part, would be the expansion of nuclear energy throughout the world, especially in my country and in China, because those are the two countries that pollute the most, but your country is doing a good job with polluting as well.

Your question was also if nuclear power can be a threat, of course a nuclear bomb or weapon is a threat. The United States and China, Russia, Israel and some others have nuclear weapons and have never used them, except in the Pacific War. There is always the danger that some irresponsible political leader will set off a nuclear catastrophe, a nuclear war, and that would be a very bad thing.

Yes, nuclear weapons should be abolished. Yes, nuclear bombs are a threat. But on the other hand, nuclear power is a possible way, maybe the only possible way, through which we can avert the disasters of climate change. So the answer to your question is yes and yes. Yes, nuclear bombs are a threat, and yes, nuclear power might save the world.

Question:

I would like to talk about the topic of peace and science and ask you how important it is for developing countries like Indonesia to catch up or be open to scientific developments in the whole world, especially in the context of globalization?

Prof. Sheldon L. Glashow:

That is a very good question and again a political one. Let me say that many countries in the world who have been quite backward, scientifically, not like Japan, because Japan has always been interested in fundamental science, but countries like China which was interested in science five hundred years ago, but not recently, have developed a very great interest in science, and the Chinese are supporting fundamental research at many levels today and so are other smaller countries, Taiwan for example and Korea, which was a very poor country when I first visited the country many years ago and is today rather wealthy and has much commitment to fundamental science, even useless science such as particle physics.

But different countries react differently. Many African countries are too poor and have not done very much, except for South Africa, which of course has a scientific establishment, and except perhaps for countries like Tunisia, Morocco and Algeria, which have a small interest in developing science. Other countries which are wealthy, like the UAE and Saudi Arabia, have the means, but so far as I know no interest in basic science, I have seen no such indication. Then there are more mysterious countries, like your country.

I am a little bit familiar with Vietnam where I have talked with the Minister of Science, and so I know that they are very interested in doing basic research, but on the other hand they are basically a poor country.

It is a question of the givers and the takers. There are some countries that accept the fruits of science, but do not contribute to them, and there are other countries which produce the fruits of science and export them to the rest of the world, and the question for your country is: What kind of country do you want to be, a giver or a taker? And that is a political issue.

Question:

Do you think the world would be better off if all countries would invest in science?

Prof. Sheldon L. Glashow:

I think it is a shared goal of humanity to try to understand the world that we live in. Whether you are religious or not, you can consider it your sacred obligation, just by being part of this wonderful and marvelous world that we inhabit, it is your duty to try and understand how it works.

Question:

I am interested in synchrotron radiation sources that you have mentioned in your talk, and I think most of us here are not familiar with it. Could you give us some suggestion to convince the Indonesian government to build one in Indonesia?

Prof. Sheldon L. Glashow:

It would be wonderful if you'd had such a facility, and the only encouragement I can offer you is what has happened in Jordan. About ten years ago European scientists, physicists, thought it would be very good if there would be a synchrotron light source in Jordan where scientists from Israel and the Middle East could collaborate, and that facility is called Sesame. Of course Jordan could not afford to build it on its own, so bits and pieces, left-overs from CERN were contributed, and finally Sesame was completed and is now operative, just recently in the last few months. Scientists from Israel, Jordan and other Arab countries are working together for the first time ever, and this is a remarkable demonstration of peace. There is no worse international situation then the one in between the Israelis and the neighboring Arab countries, and now there is this peaceful cooperation and collaboration based on science. A great example of how science can contribute to peace.

Question:

If we compare the progress on how science and technology has advanced before the 19th century and how it advances right now, is it advancing faster and is this good or bad?

Prof. Sheldon L. Glashow:

Yes, it is advancing faster now. Certainly there were huge advantages in the 19th century with the development of the automobile, the trains, and most of those were pretty positive developments for the end of the 19th century. In the 20th century things were moving much more quickly, we went from radio to television to color television, but the developments of the past 20 years have been incredibly rapid, with the explosion in information technology. The fact that all of a sudden everybody is carrying a camera, a phone and has communication to the world through the internet is absolutely wonderful.

Is it good?
I don't think it's holly good, I think it's a very dangerous situation, when propaganda can be spread very easily through the social networks – that can be good, but can also be very bad, because propaganda can serve a positive, but also an evil end. So are things are very complex now, with good and bad aspects to everything. Progress is happening much more rapidly now, God knows what the future will bring and what will come out of all these developments.

Question:

Are there any prospects for basic science research in the future? As far as I am concerned there needs to be funding from the government to support this basic research, but it seems to me that the government seems to think they don't have as much prospects as applied research.

Prof. Sheldon L. Glashow:

Let me address the issue of basic research in Indonesia. My colleague Sir Richard Roberts mentioned the wondrous diversity of life on the various many islands of this multi-island nation, all kinds of bacteria remain to be discovered and classified and made use of, plants that may have wonderful medical properties remain to be studied, animals may also be investigated, there is a huge variety of life to study from which practical things can take place.

But that’s biology let me turn to physics which is my specialty. Energy in particular, in this country you are burning fossil fuels to produce the energy you need, this country ought to make use of solar energy big time, because the country has many topographical aspects, which make it possible to store energy, to use pumped water storage, because when you have two legs at different altitudes you can pump water up when you have extra energy and get the energy out when it comes down, and this can be very efficient. Being an island nation I imagine the possible construction of salt water lakes which can pump water up from the ocean to artificial mountain lakes and store the energy in this fashion.

That way this country could turn completely to solar energy, collecting it in the daytime, storing it at night and becoming a beacon to other nations so that they too can turn to solar energy.

Maybe it’s technologically difficult, maybe it’s impossible and my idea is silly, but I was just thinking about it as a possible direction for research in energy in this country.