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Lecture for Members of Parliament, Members of Senate and Scientists

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"New Materials for the Next Millennium"

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Good morning, and thank you very much for coming to hear about "New Materials for the Next Millennium". Before I begin I would like to take a moment to thank the sponsors - the Speaker of the Senate, the Honourable Gildas Molgat; the Speaker of the House of Commons, the Honourable Gilbert Parent; the Partnership Group for Science and Engineering, especially Anne Corriveau; and the Natural Sciences and Engineering Research Council - for making this opportunity possible.

I am really going to talk to you this morning about recent developments in a field called Materials Science. This interdisciplinary subject brings together many traditional areas of science - chemistry, physics, earth sciences, biology - with engineering, in the investigation of the relationships between and among the structure and properties of materials, how these relate to materials processing and performance.

Although the international professional society of materials scientists is only 25 years old, in some sense, materials science began about two million years ago when people began to make tools from stone, at the start of the Stone Age. At this time, emphasis was on applications of materials, with no understanding of microscopic origins of material properties. Nevertheless, the possession of a stone implement certainly was an advantage to an individual.

The Stone Age ended about 5000 years ago in the Far East, with the introduction of the Bronze Age. Bronze is an alloy - a metal made up of more than one element - mostly composed of copper with up to 25% tin, with the possible addition of other elements such as lead (to make it easier to cut) and phosphorus (to strengthen it). Bronze is a much more workable material than stone, especially since it can be hammered, beaten or cast into new shapes.

Although bronze is still in use today, about three millennia ago, iron working began in Asia Minor. The Iron Age continues today. The main advantage of iron over bronze is its lower cost, bringing metallic implements into the range of the common person. The Iron Age ushered in the common use of coins, which one might say eventually led to annual budgetary pronouncements by governments! Actually, coins greatly improved trade, travel and communications, activities that even today are strongly tied to materials usage, as I hope to show you.

Throughout the Iron Age many other important new materials have been introduced. Although much has been made of the role of the printing press in advancing civilization, in some ways, the invention of papyrus about four millennia ago, is much more important, as this material allowed recording of history and improved commerce and communications. Of course, today we still make use of Canada's natural resources to produce paper, but I should like to point out that materials research in Canada includes pulp and paper, as researchers aim to reduce paper yellowing and produce better quality of recycled paper, for example.

Before we speculate about new materials for the next millennium, let's have a closer look at how new materials affect our present lives.

For a scientist, one of the most apparent changes is the way we store and handle data. Although the earliest computers such as the 1946 ENIAC [electronic numerical integrator and computer] were a big aid in this matter, with the development and application of new materials, these have been replaced computers such as a laptop, which is about 10,000 times faster, and one ten thousandth the weight, for an increase in computing power, expressed as speed for a given weight, of about 100 million!

Of course, computers do not just affect the lives of scientists and engineers, as we well know, and similarly new materials affect all our lives. For example, amorphous selenium is the photoelectronic material at the heart of the photocopier machine. New materials give new means of communication, from the CD player to modern telecommunications in which the transmitter, receiver and communications lines all rely on special materials with special properties.

Materials science also plays a role in the Arts - from the materials used to create art objects to the materials used to make musical instruments.

Of course, if you were going to have some new body parts added into you, I am sure that you would like to know that they have the required properties, including strength and biocompatibility, even if they are only going to be in your body on a temporary basis.

Even when you select your clothes, you are making use of materials science. Many of the new fabrics, for example Goretex™ and the so-called "microfibres", have been developed to have particular material properties.

New materials also affect our recreational lives, in winter and in summer, in the materials used to make recreational vehicles and sports equipment.

Now that you know more about materials science and how it affects our lives, I'd like to turn to some speculations - educated guesses - concerning new materials in the coming years. I have separated this into three headings but they really are intertwined. Of course, these are my predictions, and other materials scientists, including some in this room, likely would make different selections. Nevertheless, I think that they will give you some flavour of the current thinking and aims in this subject.

The first theme that I would like to develop is that, in future, new materials will be designed for particular properties, and tailor-made. This is a big change in approach to design of new materials, which has been primarily in the other direction, namely: *This material has these great properties, so how can we make use of them?* Of course, to make materials by design, we have to understand why they have certain properties in the first place, and this is the focus of much current research in materials chemistry and physics.

To illustrate the way in which materials can be designed to have particular properties, I'd like to take an example close to my own research interests, thermal properties of materials. The example I would like to use involves heat storage, but first I need to give you a little background.

We all know that if a material is heated, its heat content increases. If it happens to melt, this will take extra heat. These properties can and are used to advantage in storing energy for later recovery. A commercial product, known as a ReHeater™ makes use of this exact property. When the melt is supercooled, it is unstable, wanting to be solid, and crystallization can be activated by bending an imbedded piece of metal. This causes the solid to form, giving off heat. (Remember that it took heat to form the liquid, so it is given back off when it solidifies.)

This same principle can be used to heat whole regions such as the Minato Mirai 21 district in Yokohama, Japan. This area makes use of a district heating plant in which cheaper night-time electricity is used to freeze a tank of water, and then in the daytime, a solution exchanges energy with the ice, melting some of it, and producing chilled water for air conditioning the buildings.

While air conditioning is important in the summer in most parts of Canada, at this time of year we are usually more concerned about heating. However, special heat storage materials can be used in this same way, heating up during the daytime in a solar home and then radiating this stored heat at night. A solar home near my own house in Halifax has been built to accommodate new heat storage materials, developed in my laboratory, in an NSERC-sponsored project. These particular materials have been designed to have special heat storage properties, after years of fundamental research concerning the principles associated with heat storage materials. Now we are working with companies such as Mitsubishi Chemicals to tailor-make better materials for their heat storage materials markets.

I'd like to spend a few more minutes on another thermal property, as it relates to tailor-made materials. Maybe some of you own coolers that plug into an outlet to get their cooling power. They don't work on a conventional refrigeration cycle, but have a solid-state device which cools by the so-called thermoelectric effect. The main requirements are that the thermoelectric materials must be good conductors of electricity, and poor conductors of heat (conditions that are usually at odds with each other). However, now that we understand more about how heat is conducted in materials, industry, such as MARLOW INDUSTRIES of Dallas, Texas, is making use of this knowledge - and this is an area in which my group has made substantial contributions, along with the NRC labs here in Ottawa - to produce new thermoelectric materials. We still have much to learn, but someday new thermoelectric materials could be so powerful that every home would have a rapid chiller, equivalent to the rapid heating effects that we get with a microwave oven. Before I leave the topic of heat conduction - one of my personal favourite subjects - I should also mention that heat dissipation is one of the main limitations to the development of new computers: as the storage and calculation capacity goes up, so does the need to dissipate heat, and development of appropriate materials and devices is an active area of materials science research at present.

We are not yet at the stage of tailor-making all new materials, because we don't yet understand how all the present materials get their properties. For example, the so-called high-temperature superconductors are not yet understood. Superconducting materials conduct electricity perfectly. The connection between electric and magnetic properties makes a superconductor strongly repel a magnet. In principle, this can lead to such fascinating devices as magnetically levitated trains, running on a magnetic cushion above superconducting tracks. Unfortunately, the known superconductors so far only exist at very low temperatures, so far the hottest one is at -140^{o}C! Until we understand how superconductors work, it is unlikely that room-temperature superconductivity will be achieved.

However, we do understand the principles of operation of many new materials, and this fundamental research has led to such recent applications as a fully plastic light source and blue lasers. In addition, new energy sources are being used to advantage, such as the prototype bus powered by hydrogen fuel cells, developed by Ballard Power in Vancouver.

Although we have long understood the role of atoms in forming solid structures, new types of microscopes, invented in 1986, allow us to see atoms for the first time. Now we know that ordinary copper surfaces are not atomically flat, but the more fascinating thing is that now we can move atoms around one at a time. The images created are almost in the realm of art, and one scientist has a particular signature piece in which he spelled out the name of his employer - IBM - with xenon atoms on nickel.

Now that we are gaining control the structures of materials down to atomic scale, we will be able to produce materials with specially tailored chemical properties even more specific than zeolites that are used to transform hydrocarbons for the petroleum industry. Furthermore, as we learn more about ultra-small (atomic), electronic devices, they will make present electronic devices look both gigantic and antiquated!

My second prediction for future materials being "smart" is already a reality. By smart materials, I mean those that change their properties in response to their environment. Plastics have been developed that change their shape with electric field, allowing for robotic fingers, and new metals can remember their shape, allowing applications as diverse as showerheads that shut off when the water temperature suddenly changes and car fenders that can be induced to remember their pre-collision shape by heating with a hair dryer! Other responsive materials change mechanical properties when under tension - and can lead to buildings that stabilize themselves during earthquakes. Based on Canadian research, there are already bridges in place that sense and respond to changes in loads and wind conditions, and smart skis respond to snow conditions. Some smart materials change colour with temperature. This so-called thermochromism can be used to produce road signs that would be a known colour when the temperatures fall below zero, to warn of potentially icy conditions.

My final prediction concerning future materials involves more complex materials, those using many different types of materials, to achieve the goal of given properties or performance characteristics. These are collectively known as "composite materials."

One of the most important composite materials of this century has been the transistor. The first transistor was made 51 years ago, and it has its special electronic properties because it is composed of different types of semiconductor materials.

In trying to design new composites, we are mimicking Nature, in the composite materials of ivory, and spider webs.

Nature also provides other interesting materials, like the strong adhesive in barnacles, and learning lessons from Nature's products is one of the main aims of current materials science research.

Not only does Nature make interesting materials, but also interesting architectures that some Canadian researchers have had recent success in mimicking.

For those of you in the audience who make or influence decisions concerning national science issues, I should mention that Materials Science involves a wide variety of areas of science and engineering, but one common element is materials characterization, and there is a great need for state-of-the-art equipment, both lab-based, and for regional, national and international use. If you happen to be requested for input concerning such facilities, I hope that you will now know a little more about why researchers would require specialized equipment, to study the structure and properties of new materials, towards producing new materials for the next millennium.

It has been said [by Tadahiro Sekimoto, the former President of Nippon Electric Company] that those who dominate materials, dominate technology. In the distant past, Canada's role in materials has been primarily in the supply of raw materials, such as wood and minerals. The future for this great country is in adding value. The value added is intellectual value, so that we can go into the future having new materials and a high degree of productivity for Canada.

Further Reading:

"Stuff" by Ivan Amato, BasicBooks, New York (1997).

"Made to Measure" by Philip Ball, Princeton University Press, Princeton (1997).

"The Cambridge Guide to the Material World" by Rodney Cotterill, Cambridge University Press, Cambridge (1985).

"Understanding Materials Science" by Rolf E. Hummel, Springer, New York (1998).

"The Substance of Civilization" by Stephen L. Sass, Arcade Publishing Inc., New York (1998).

"Properties of Materials" by Mary Anne White, Oxford University Press, New York (1999).