ENR212 Lecture 2 Notes and Slides

Slide 1

Hello everyone, and welcome to lecture summary two of Manufacturing Processes. (This lecture will cover content from chapter 2 of the textbook.)

In this lecture, we will introduce materials in manufacturing. We will address the following three questions: first, what is an atom, and what are the bondings between molecules, and between atoms? Second, what are crystalline structures, and how do atoms arrange themselves in a crystalline structure? Third, what are amorphous structures and what are the features of amorphous materials?

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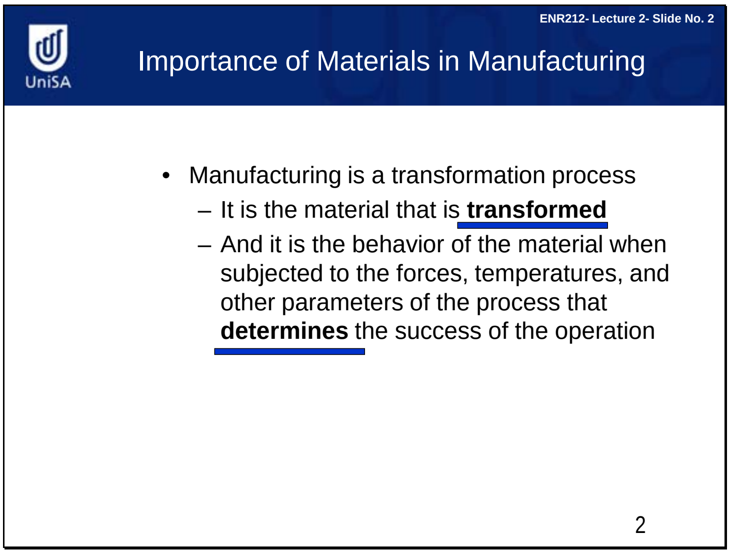
Slide 2



Materials are of great importance in manufacturing for two reasons. First, the aim of manufacturing is to transform materials from one state to another more advanced state with increased value. Second, it is the material properties that determine the manufacturing processes, such as the set up of machines.

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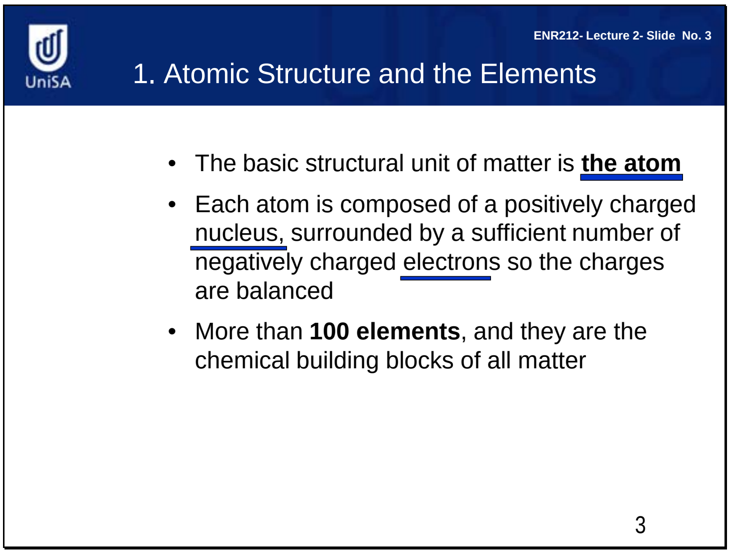

There are two levels of structural unit: atom and molecule. The basic structural unit of a material is the atom. Each atom comprises a dense nucleus and electrons. The nucleus includes protons and a neutron. There are more than 100 elements in total.

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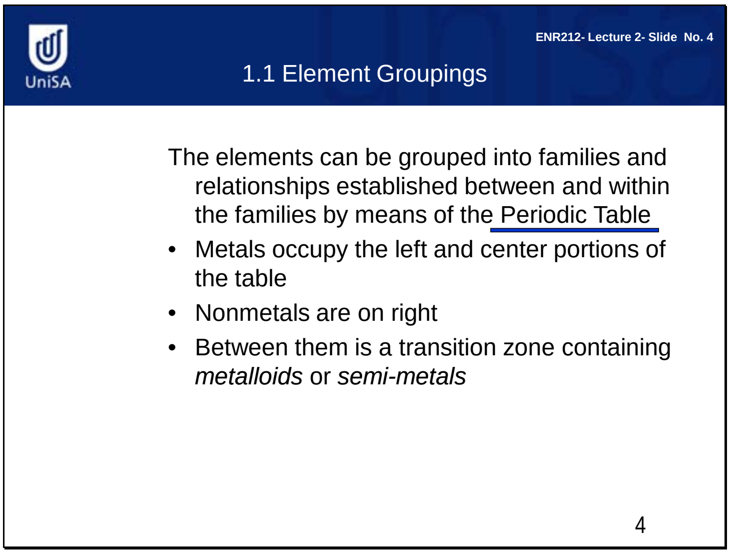

Based upon the atomic number and the outermost electron configuration of elements, these elements are grouped and classified in the Periodic table. Note that the atomic number of an atom is the numbers of protons in this atom.

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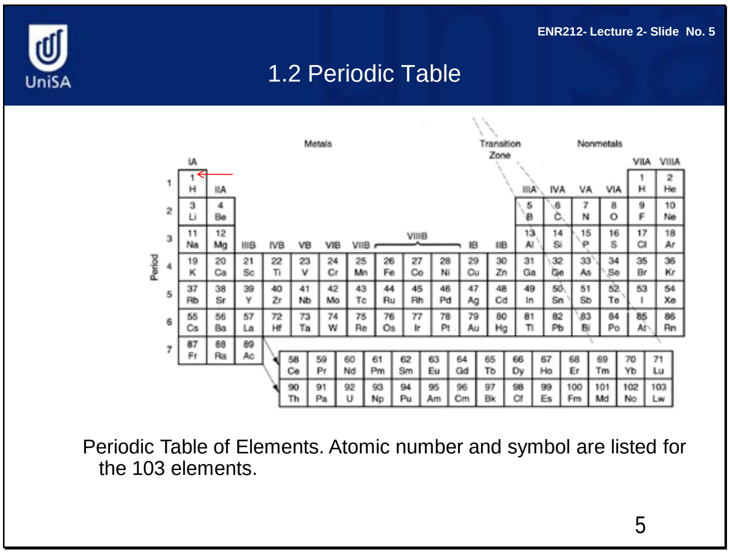

In the periodic table, all elements are sequenced according to their atomic number. For example, the top right element is helium. The value on the top of Helium is the atomic number of Helium.

The three types of elements are metals, non-metals and semi-metals. Non-metals are located in the right part of the table. Metals are in the left and in the middle. Between the middle and the right part of the table is the transition zone, which contains semi-metals such as silicon.

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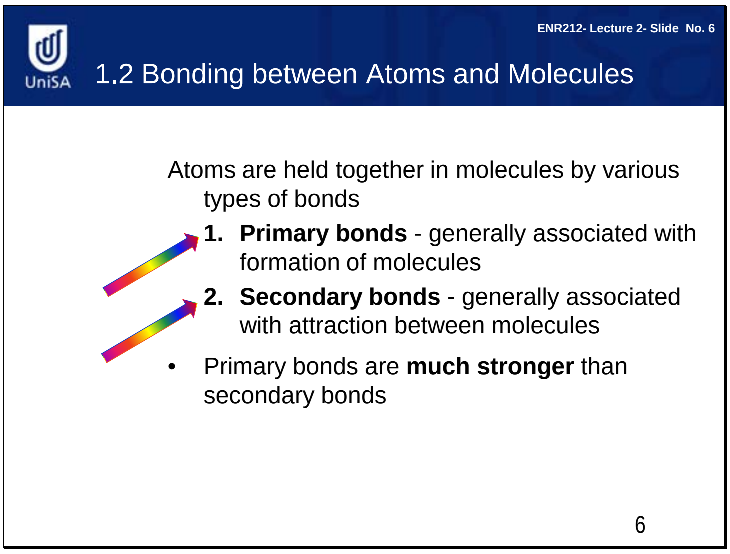

There are two levels of interaction in materials. Primary bonds exist between atoms. Secondary bonds exist between molecules. In general, primary bonds are much stronger than secondary bonds. This explains why metals generally have higher absolute strength than polymers.

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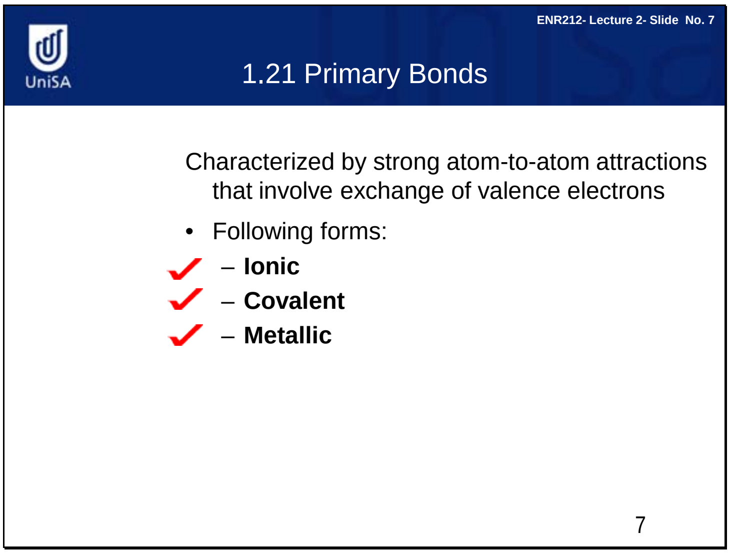

Primary bonds include Ionic bonds, covalent bonds and metallic bonds.

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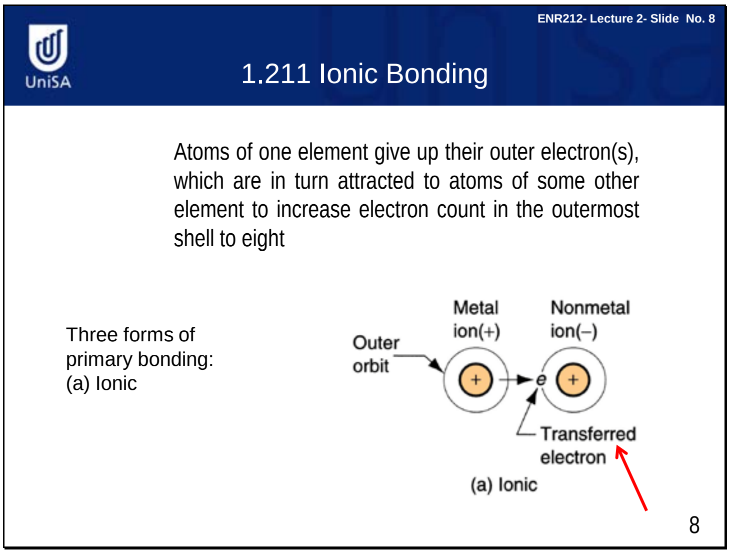

Ionic bonding involves electron transfers. As you can see in this image, electrons are transferred from the metal ion to the non-metal ion. The electrons are only transferred between these two ions, not to other atoms. This means that the ionic bonding is directional, and it explains why ionic bonding materials are not electrically and thermally conductive.

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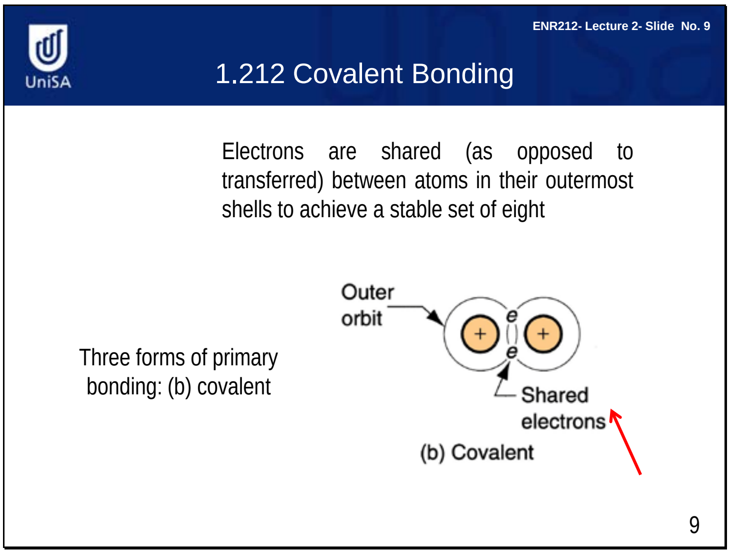

Shared electrons are involved in covalent bonding. As you see in this figure, a pair of electrons is shared by two atoms. This means the covalent bonding is directional. Therefore, covalent bonding such as in wood is not electrically and thermally conductive.

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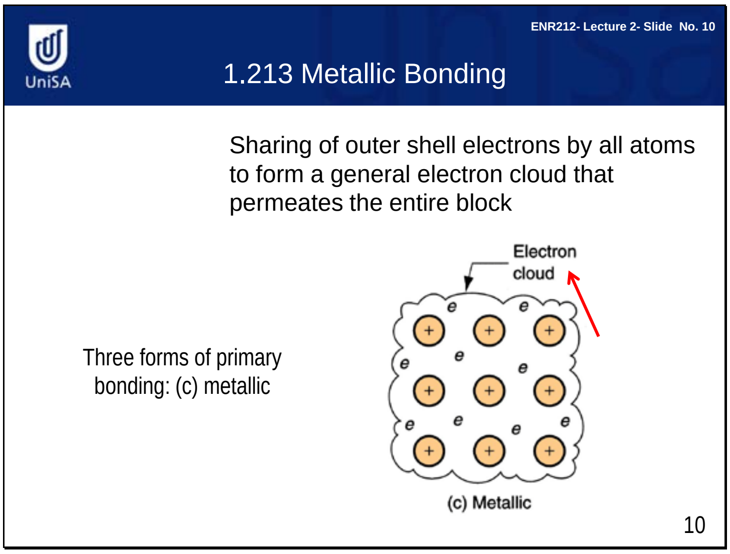

In metallic materials, each atom contributes at least an electron, so there are a great many electrons in a metal. These electrons have complete freedom. That is, one electron is able to move from one atom to another. Therefore, metallic bonding is not directional. This explains why metallic materials are electrically and thermally conductive and why metals are normally stronger than organic materials such as wood, which comprises covalent bonding.

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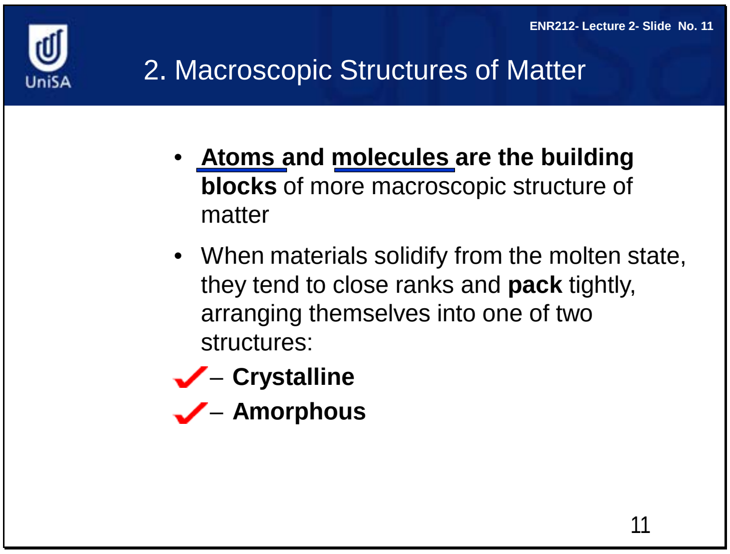

The building blocks of materials include atoms and molecules. Atoms are the building blocks of metals, while molecules are the building blocks of polymers. Materials are classified into crystalline and amorphous, according to how the atoms arrange themselves.

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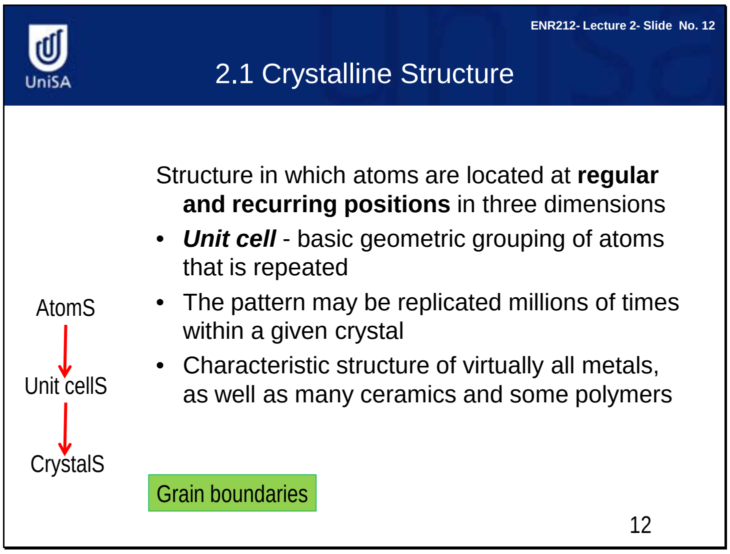

In a crystalline structure, the atoms are arranged at regular and recurring positions. That is, the atoms in a crystalline structure are disordered. Atoms are combined into unit cells. Unit cells are combined to produce crystals. The size of atoms is around 0.1 to 0.13 nanometers. The average size of unit cells is around 0.4 to 0.6 nanometers. The size of crystals range from nanometers to millimeters.

The combination between atoms and the combination between unit cells is very good. However, the combination between crystals is not good at all, and produces defects. The area between crystals is called the grain boundary. Grain boundaries are defects of metals. However, grain boundaries are desireable in manufacturing, because more grain boundaries means lower yield strength and higher ductility. This reduces manufacturing costs.

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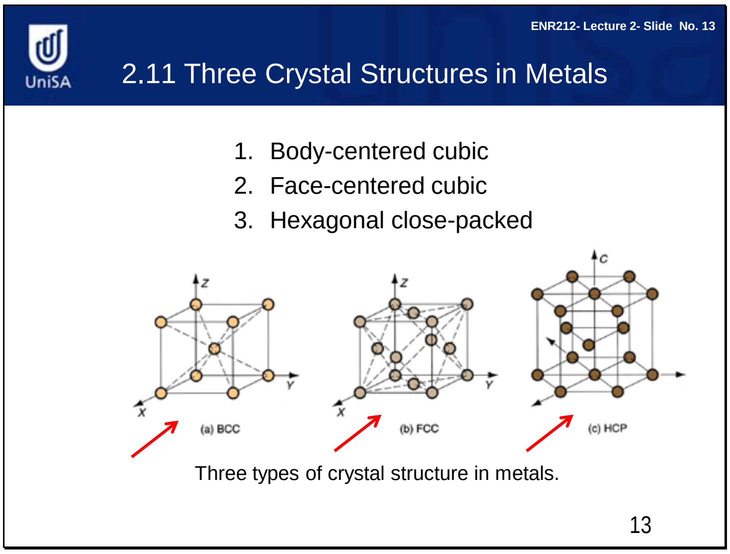

There are three crystal structures for metals: body-centered cubic structure, face-centered cubic structure and hexagonal close-packed structure.

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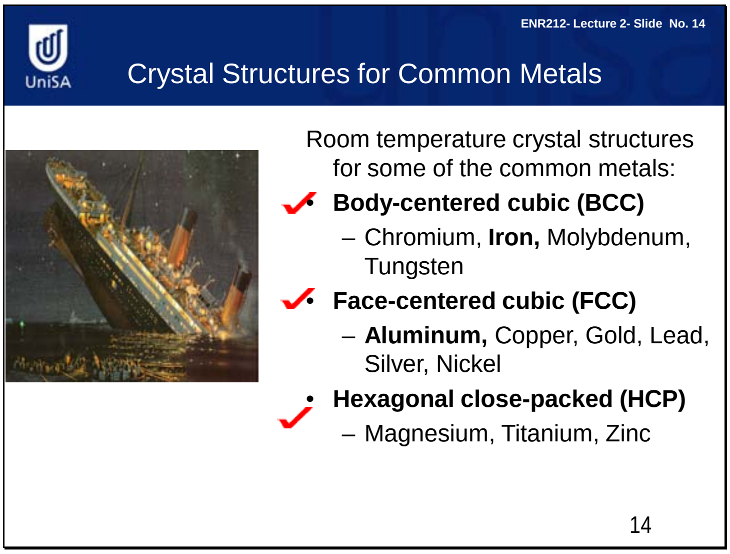

Body-centered cubic materials, such as iron, have very good strength at room temperature, but their fracture toughness at low temperature is poor. Do you remember the movie 'Titanic'. It was about a ship which sank, leading to the loss of 2000 lives. It sank because it was made of iron, which has low toughness at low temperatures in icy water.

Face-centered materials, such as aluminium, are not as strong as body-centered cubic materials at room temperature. However, aluminium has very good toughness at low temperature. If the Titanic was made of aluminium instead of iron, it would not have sunk.

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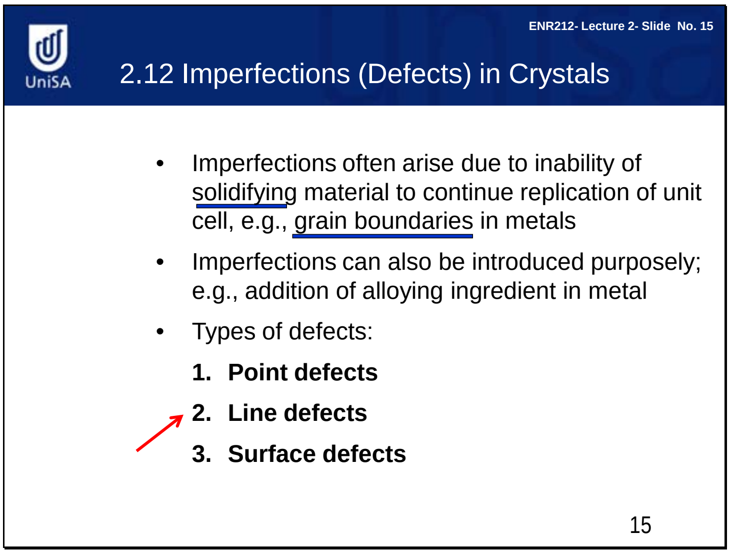

During solidification processes, imperfection or defects in crystals of metals are produced when the temperature is reduced from melting temperature to room temperature. An example of defects is grain boundaries. As we have discussed, grain boundaries are the area between crystals and grains. There are three types of defects: point defects, line defects and surface defects. Surface defects are actually grain boundaries.

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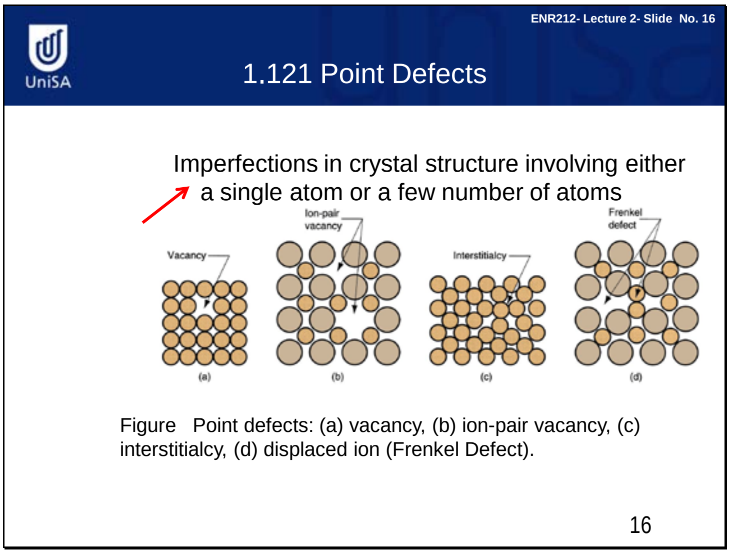

Point defects are imperfections in the crystal structure of metals, in which only one or a few atoms are missing.

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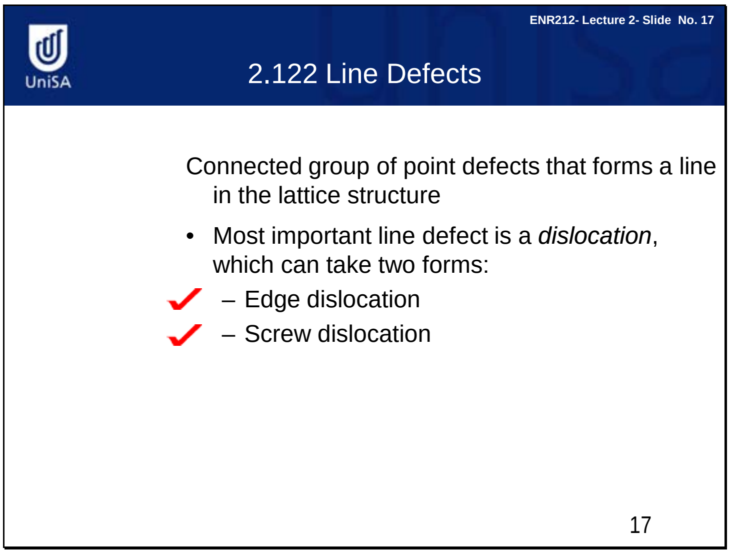

Line defects are connected point defects that form a line in the lattice. Line defects are classified into edge dislocations and screw dislocations.

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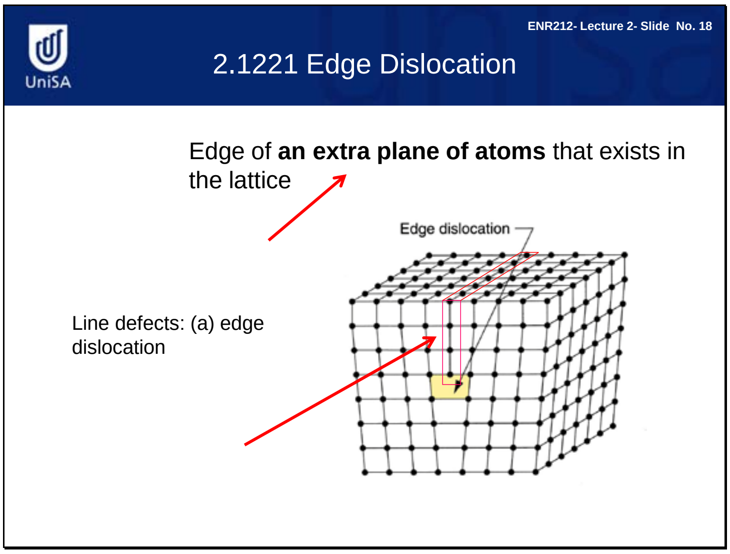

An edge dislocation is the edge of an extra plane of atoms that exists in the lattice. In this image, the area included in the red rectangle represents an edge dislocation.

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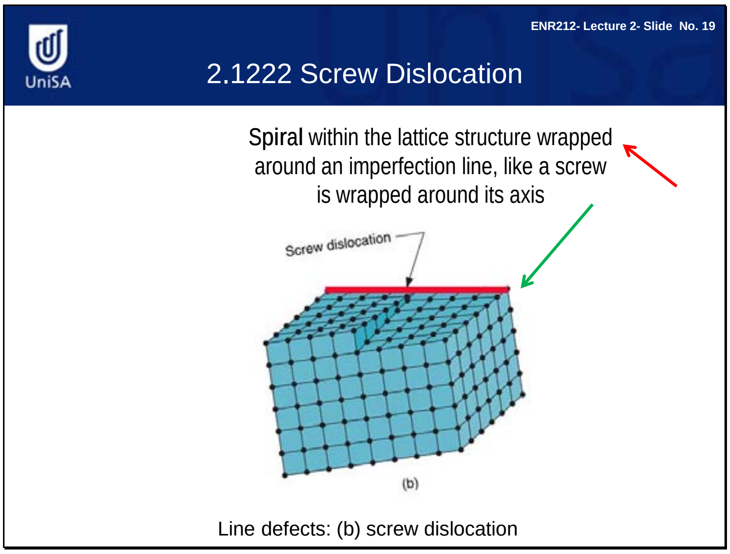

A screw dislocation is a spiral in the lattice structure which is wrapped around an imperfection line, as you can see in this image. The red line represents an imperfection line.

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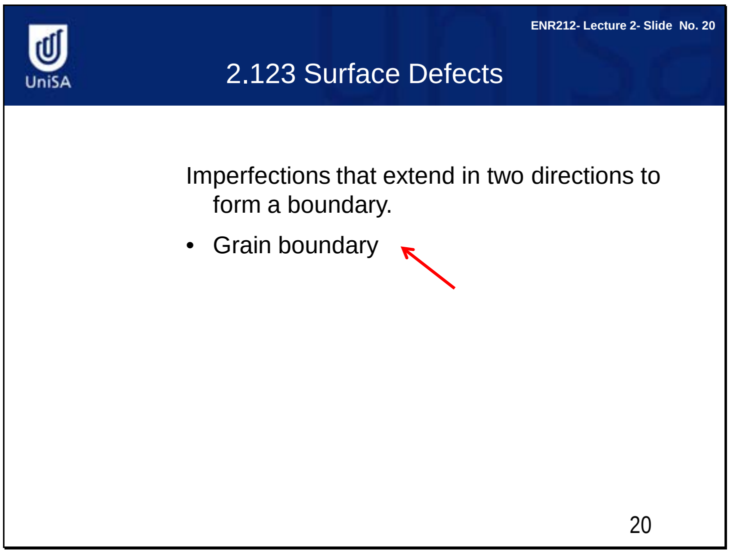

Surface defects are actually grain boundaries. The grain boundaries are just areas between crystals, between the grains of metals.

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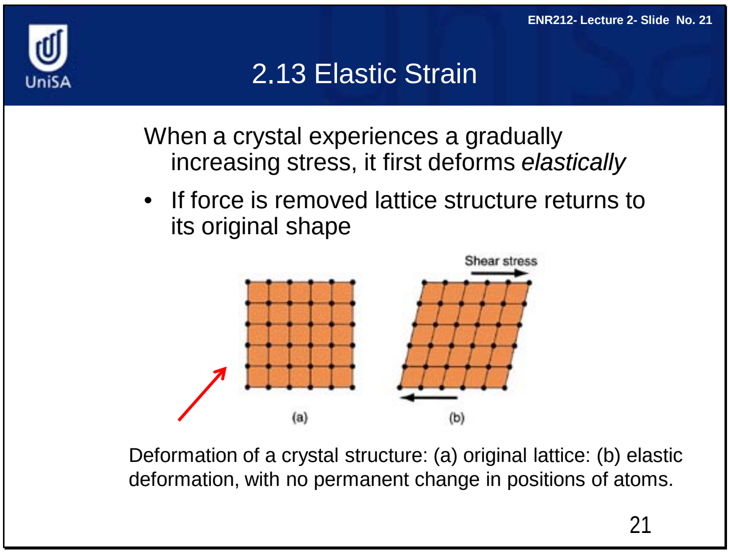

There are two types of deformation of materials: elastic deformation and plastic deformation. An example of elastic deformation is the elongation of a rubber band. Plastic deformation examples include the fracture of ductile thermal plastics.

This image shows the elastic deformation of a crystal lattice. Under shear loading and stress, the lattice structure changes slightly. Upon removal of the loading, the lattice is able to revert back to its original shape immediately and completely. This is called elastic deformation or elastic strain.

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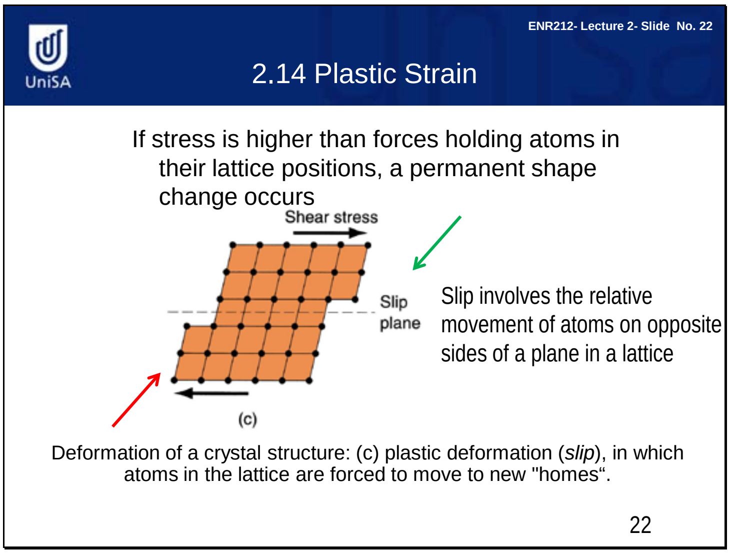

Plastic strain is similar to plastic deformation. The deformation produced is not recoverable. This image shows plastic strain in a lattice. Under increasing shear stress, plastic deformation occurs. This plastic deformation is permanent and not recoverable. This kind of deformation is called slip. What is slip? Slip involves the relative movement of atoms on opposite sides of a plane in a lattice.

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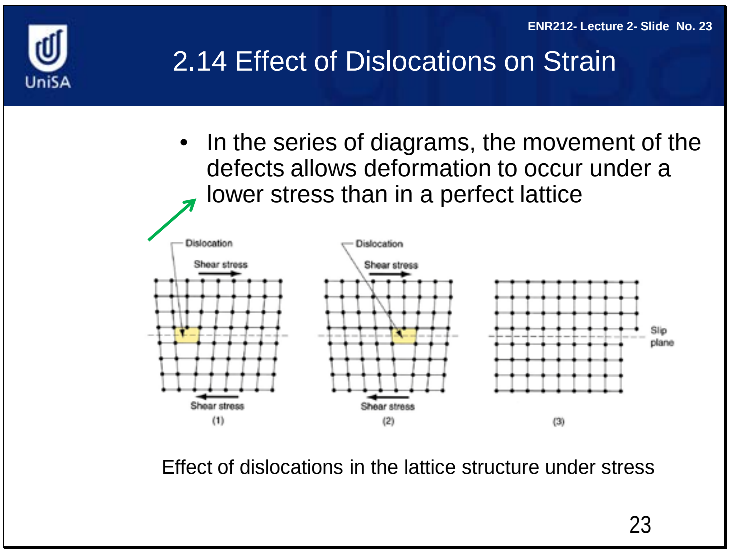

As advised before, dislocations and defects are important in manufacturing. Defects and dislocations are desired, because more dislocations means lower yield strength, which means lower cutting force is needed in manufacturing. This saves energy and time.

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2.141 Slip on a Macroscopic Scale

- Slip occurs many times over throughout the metal when subjected to a deforming load, thus causing it to exhibit its macroscopic behavior in the stress-strain relationship
- Dislocations are a good-news-bad-news situation
  - Good news in manufacturing – the metal is easier to form
  - Bad news in design – the metal is not as strong as the designer would like

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However, dislocation or defects are a double-edge sword. Dislocations are desired in manufacturing, because they reduce the manufacturing cost. However, dislocations are not good in material design, because dislocation reduces the strength of materials.

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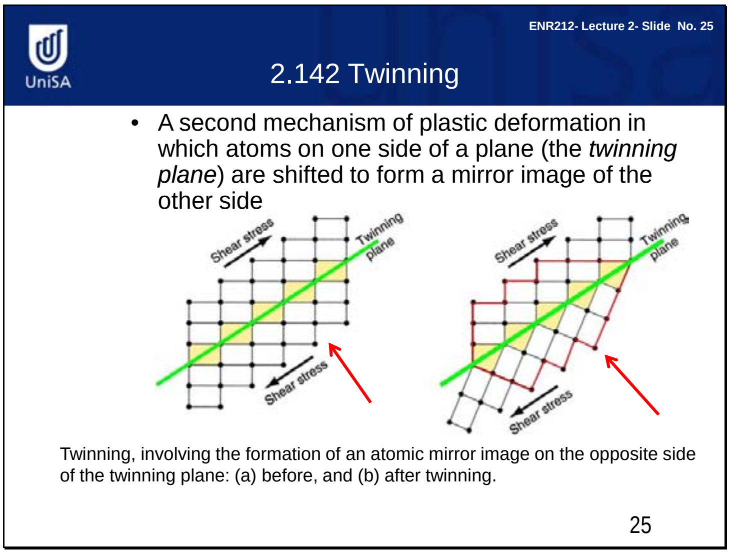

Slip is the first mechanism of plastic deformation. The second mechanism is twinning. The left image shows a lattice before plastic deformation. The green line represents a twinning plane. You can see the lattice geometry above the plane is similar to the lattice below the plane. Now look at the second image. After the shear deformation, the geometry of the lattice above the plane is different to the lattice below the plane. This phenomenon is called twinning.

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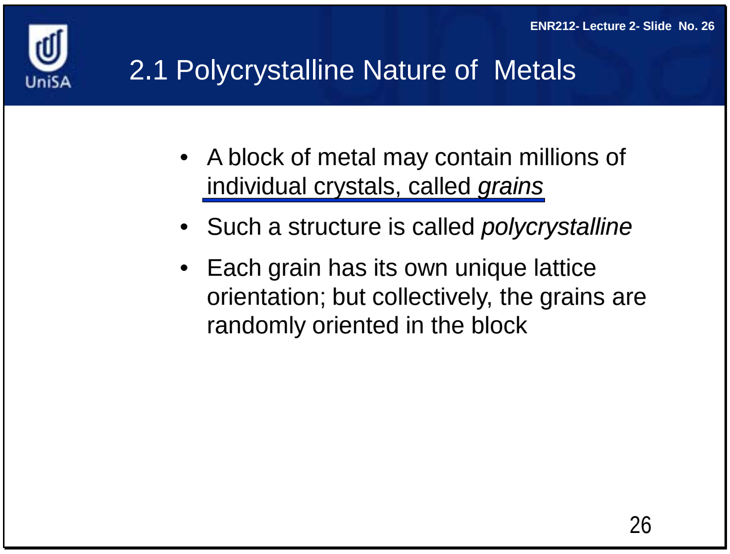

Metals are crystalline materials. Metals contain crystals. These crystals are also called grains. Here are two questions for you.
First, are all metals crystalline. Yes or no? The answer is no.
Second, are metals crystalline at room temperature. Yes or no? The answer is no, because mercury is liquid at room temperature.

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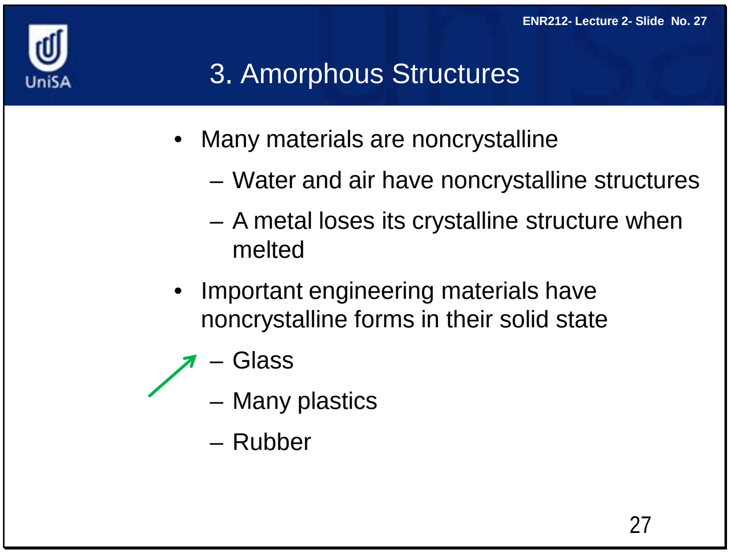

Metals have crystalline structures. However, polymers are different. Some are crystalline, some are semi-crystalline and some are just amorphous. Amorphous materials should be transparent (such as glass).

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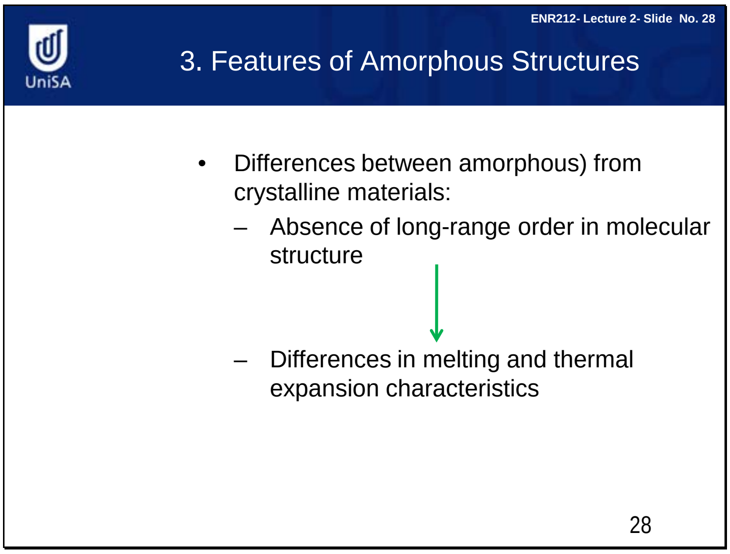

We have looked at crystalline structure. In crystalline structures, the atoms are arranged at regular and recurring positions. In amorphous structures, there is no long-range order in molecular structure. This means that there are huge differences in melting and thermal expansion characteristics.

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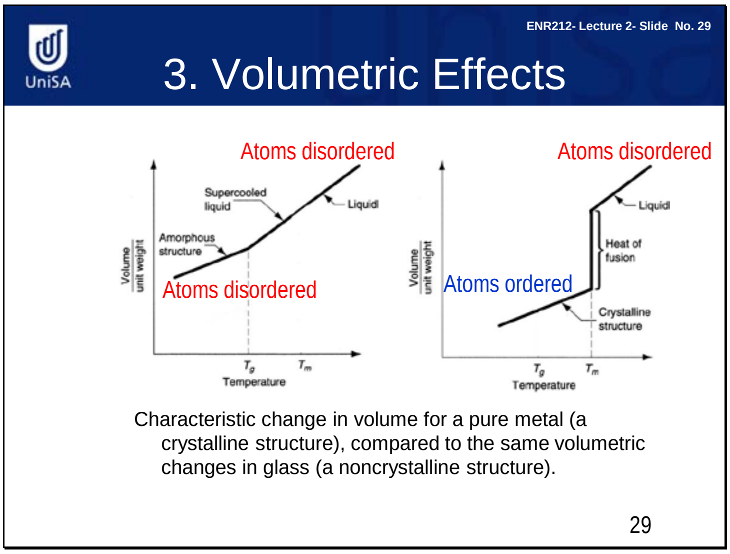

An amorphous material shows very different thermal behaviour to a crystalline material. For example, with temperature changes, the volume change for an amorphous material is different to the volume change for a crystalline material.

The right image shows you the volume change for a crystalline material. In the solid state of a crystalline material, all atoms are in a regular and recurring pattern; this means that all atoms are in an ordered state in the solid state. On the other hand, in the liquid state of a crystalline material, the regular and recurring pattern has disappeared; this means that all atoms are in a disordered state in the liquid. Therefore, when the material changes from liquid to solid, the atoms need energy and time to change from a disordered state to an ordered state. This is similar to what you do every day. You need time to make a messy room neat and tidy, you need time to change a disordered room into an ordered room. Atoms need time and energy to get themselves ordered at the melting temperature when the crystalline material changes from liquid to solid, and this leads to an obvious volume change at melting temperature.

The left image shows you the volume change with temperature for an amorphous material. Since the atoms of the amorphous material are in an disordered state in both the solid and liquid state, there is no obvious volume change at temperature.

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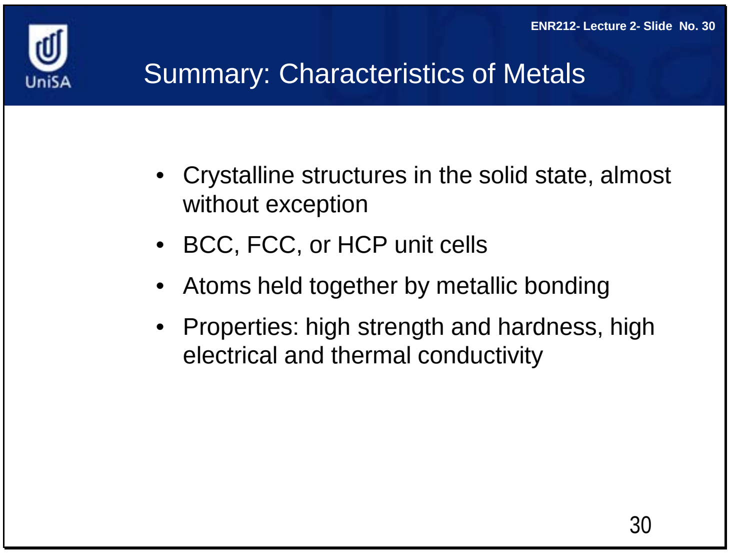

Metals are crystalline in their solid state. Metal atoms are held together by metallic bonding. There are a large number of free electrons, and this sets the high strength, high stiffness and high electrical and thermal conductivity of metal.

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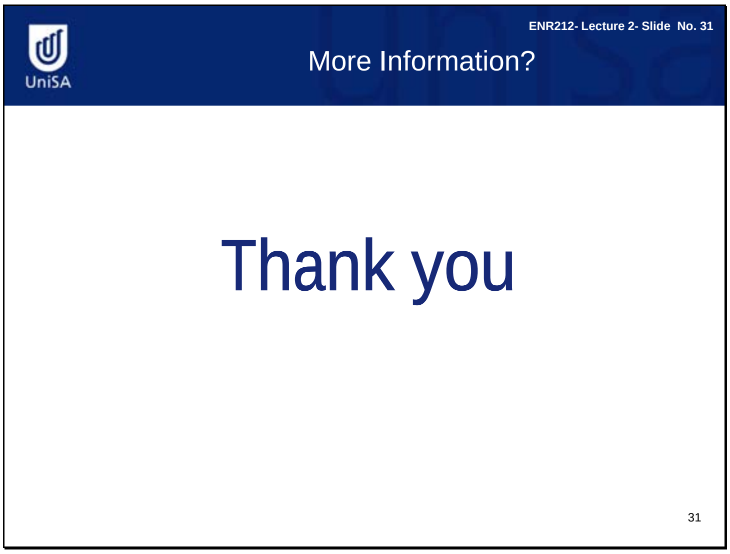

Thanks for your attention.