

Engineering Science (EG-086)

Introduction

Lecturer: Dr Zak Abdallah works with Rolls Royce University Tech Centre in materials and research as well as Swansea materials Research and Development

I am required to email him to make an appointment if i wish to speak with him. I have no thursday lectures and there are no Monday lectures unless explicitly stated.

Recommended reading

- Physics for scientists and engineers : a strategic approach with modern physics / Randall D. Knight.

Testing

There are two online assesments worth 25% in total, with a final exam in January worth 75%.

1 Quantities, Units and Dimesnsions 04/10/18

Random Error - Unpredictable and can be reduced by averaging multiple results

Systematic Error - Predictably inaccurate, this is cause by the the measurement device not being calibrated correctly. It is consistently wrong, so, for example, will always be too high.

2 States of Matter

10/10/17

Kinetic Theory of Matter

- All matter is made of atoms. The electrostatic interaction between these atoms results in potential energy
- The average kinetic energy of the atoms/ molecules is the temperature of the substance. As the thermal energy increases the rate of motion of the molecules/atoms increases.
- When in the gaseous state, atoms can move and collide elastically with each other and the surrounding container. The rate of these collisions is referred to as pressure.

$$\text{Potential Energy} + \text{Kinetic Energy} = \text{Internal Energy}$$

Binding forces exist between atoms which hold them together, such as Ionic, Covalent, and Metallic bonding. Repulsive electrostatic forces push atoms apart. These are caused by the electrons of each atom repelling each other.

Crystalline solids are very atomically uniform, while Amorphous solids have a less uniform structure.

Heat is a measure of Thermal Energy, normally added to a substance. Temperature is the average Kinetic Energy of the atoms. Therefore, Heat \neq Temperature

Gas Laws

Boyle's Law states that for a constant temperature: $\frac{V_1}{P_2} = \frac{V_2}{P_1}$

Charles' Law states that for a constant pressure: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Amonton's Law states that for a constant volume: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Avogadro's Law states that for a constant pressure and temperature: $\frac{V_1}{n_1} = \frac{V_2}{n_2}$
where n = number of moles

Ideal Gas Law

$$PV = nRT$$

Where:

P - Pressure (Pa)

V - Volume (m³)

n - Number of moles (mol)

R - Gas constant (8.314 J/mol K)

T - Temperature (K)

This can also be written as:

$$PV = mRT$$

Where:

P - Pressure (Pa)

V - Volume (m³)

m - Mass(Kg)

R - Gas constant (8.314 J/mol K)

T - Temperature (K)

Phase Change

Phase \equiv State

- If no phase change is involved, all energy added to matter in the form of heat increases the kinetic energy of the molecules, meaning the temperature increases
- During a phase change the temperature remains fixed until the phase change is complete, despite energy being added through heat.
- All of this energy is used to change the potential energy, while the kinetic energy remains the same
- Both phases are said to be in thermal equilibrium during this transition

3 Thermal properties of matter 17/10/17

Conduction

Heat flows from the hot region to the colder region without any net movement of the actual substance. This is how heat is transferred through metals. The atoms at the hot end of the metal have a higher average kinetic energy compared to their colder neighbours. They then collide with these neighbours, transferring some of the kinetic energy.

This occurs most in solids as the atoms are closer together so they collide more.

$$Q = kA \frac{T_H - T_C}{L}$$

Where:

Q = Heat energy (W)

k = Thermal conductivity coefficient ($\frac{W}{mK}$)

A = Area heat is being transferred through

T_H = The hot temperature

T_C = The cold temperature

L = Length (or thickness) heat is being transferred through

Convection

Convection of heat is transfer of thermal energy from a hotter to a colder region through mass motion of a fluid medium. Natural convection is caused by density differences in a fluid due to temperature differences. An example of this would be water being heated in a pan, the water at the bottom receives heat, becomes less dense and rises. The cooler, denser air falls to replace it, and this process then repeats, forming a convection current until all the water is the same temperature.

Forced convection is where fluid motion is generated by an external source, such as a fan or pump.

$$Q = hA(T_{body} - T_{surr})$$

Where:

Q = Heat energy(W)

T_{body} = Temperature of the body(K)

T_{surr} = Temperature of the surroundings(K)

A = The area that heat is being transfered away from(m^2)

h = Convection heat transfer coefficient($\frac{W}{m^2K}$)

Radiation

Radiation is heat transfer by electromagnetic waves with no intervening medium. Warmth recieved from the sun, from glowing coals, or from an electric bulb is all through radiation. While radiation heat transfer can occur through a fluid (such as air) it doesn't require one, unlike the other methods of heat transfer.

When thermal radiation hits a substance it can either be absorbed, transmitted (passes through), or reflected by it. And substance that is a good emitter tends to be a good absorber, and visa versa. Mirrored or polished surfaces are poor at this while matt black surfaces are good. A substance that absorbs all alectromagnetic radiation is called a black body.

The transfer of thermal radiation is described by Stefan's law, such that:

$$Q = \epsilon \sigma A T^4$$

Where:

Q = Heat energy(W)

T = Temperature of the body(K)

A = The area heat is being transfered from(m^2)

σ = The Stefan-Boltzmann constant($5.67 * 10^{-8} \frac{W}{m^2K^4}$)

ϵ = The emissivity of the object (between 0 and 1)

Heat Capacity

Heat capacity is the the amount of energy required to raise the temperature of an object by unit quantity (1K or 1°C). This is dominant when no phase change is involved.

$$Q = C\Delta T$$

Where:

$$Q = \text{Heat energy}(J)$$

$$C = \text{Specific heat coefficient}\left(\frac{J}{K}\right)$$

$$\Delta T = \text{Change in temperature}(K)$$

Specific heat capacity is the amount of energy required to raise 1Kg of a substance by 1°K.

$$Q = mC_s\Delta T$$

Where:

$$Q = \text{Heat energy}(J)$$

$$C_s = \text{Specific heat capacity}\left(\frac{J}{kgK}\right)$$

$$\Delta T = \text{Change in temperature}(K)$$

Latent Heat

Latent heat (L) is the amount of energy absorbed or released when a phase change occurs.

The heat supplied can be calculated using:

$$Q = mL$$

Where:

$$Q = \text{Heat energy}(J)$$

$$m = \text{Mass of Substance}(kg)$$

$$L = \text{Latent heat of the substance}\left(\frac{J}{kg}\right)$$

Latent Heat of Fusion (L_f) is the amount of energy absorbed through heat when unit mass of a substance changes from solid to liquid.

Latent Heat of Vapourisation (L_v) is the amount of energy absorbed through heat when unit mass of a substance changes from liquid to gas.

Latent Heat of Sublimation (L_s) is the amount of energy absorbed through heat when unit mass of a substance changes from solid to gas.

4 Thermodynamics

There are three different types of systems in thermodynamics. These describe how an object interacts with its surroundings. These types of systems are:

Isolated	Closed	Open
No matter can transfer	No matter can transfer	Matter can transfer
No heat can transfer	Heat can transfer	Heat can transfer

Work

P-V Diagram

The P-V diagram relates the pressure (P) to the volume (V). The work done is the area under the P-V diagram. This means that if P is constant and V is changing then the work is:

$$W = P\Delta V$$

If V is constant while P is changing, then $\Delta V = 0$, meaning the work done is:

$$W = P\Delta V = 0$$

If both P and V are changing, then the work is:

$$W = \int P dV$$

Laws of Thermodynamics

The First Law

This law defines the relationship between internal energy (ΔU) of a system and exchange of energy with the environment in the form of heat (Q) and work (W).

The total energy entering a system through heat (Q) is used both to change the internal energy (ΔU) and work done (W) on the environment by the system.

$$Q = \Delta U + W \rightarrow \Delta U = Q - W$$

Q is positive if heat is added to the system while W is positive if work is generated by the system.

When a system changes from an initial state to a final state it passes through a series of intermediate states, called a path. The work done by a system is dependant not only on the initial and final state, but also on the path taken. Similarly the amount of heat entering or exiting the system also depends on the path taken.

The Second Law

The Third Law

Thermodynamic Process

$$Q = \Delta U + W$$

Adiabetic - A process where $Q = 0$

Isothermal - A process where $T = \text{constant}$

Isobaric - A process where $P = \text{constant}$

Isochoric - A process where $V = \text{constant}$

Cyclic - A process that returns to its original state

Heat Engine

The cyclic process allows the conversion of one form of energy (heat) into another (work). This process forms the basis for conversion of thermal energy from burning fuel into mechanical work. All engines that burn a substance are heat engines.

Each cycle a heat engine absorbs heat (Q_1) from a hot reservoir at a high temperature. Some of this is converted into mechanical work (W) while the remaining heat (Q_2) is discarded into the cold reservoir. In a complete cycle the system returns to its original state, so $\Delta U = 0$. The net work done by the engine can be defined as

All heat engines are less than 100% efficient

5 Electrostatics

31/10/17

The fundamental electric charge is that on an electron (an electron volt). Charge can be induced on certain objects by conduction or friction, such as by rubbing a glass rod with a silk cloth. This is because the silk cloth tears electrons away from the glass rod. The unit of charge Q is a coulomb, C.

Coulombs law

The magnitude of the electrostatic force, F , between two point charges, Q_1 and Q_2 , is directly proportional to the product of their charges and inversely proportional to the square of their separation, r .

$$F = k \frac{Q_1 Q_2}{r^2}$$

Or

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

Where:

$$k = 9.0 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

$$\epsilon_0(\text{permittivity}) = 8.85 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2}$$

It is important to ignore the sign of the charges when using these equations.

The direction of the force is dependant upon the charges of the points (positives repel each other etc.). The charge of an electron is a constant, $Q_{\text{electron}} = 1.6 \times 10^{-19} \text{ C}$

Principle of Superposition

Coulombs law only gives the force on a charge due to one other charge. If several charges are present you need to resolve forces horizontally (F_H) and vertically (F_V) and then find the resultant (R) and the direction (Θ) of the net force.

$$R = \sqrt{F_H^2 + F_V^2} \quad \Theta = \tan^{-1} \left(\frac{F_V}{F_H} \right)$$

Electric Fields

Electric fields are measured in Newton per Coulomb (N/C). If a second charge, Q_2 is placed near the first charge Q_1 , it experiences a force exerted by the electrical field of Q_1 . From coulombs law we can calculate the electric field at a distance r from a single point charge:

$$E = k \frac{Q}{r^2} \quad \text{Or} \quad E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

6 Electricity

6.1 Electric Current

In order for charge to move between two points there needs to be a p.d. between the points and there should be a carrier material (a conductor connecting the two points). Metals are good conductors due to their cloud of free electrons that can carry charge. The amount of charges moving per unit time is call the ‘electric current’.

$$I = \frac{Q}{t}$$

Where:

I = current (A)

Q = charge (C)

t = time (s)

6.2 Electric Resistivity and Resistance

Electrons will move when ther is a p.d. present in a closed circuit. This motion will involve collisions and this results in resistance and heating within the conducting wire. This is refered to as resisitivity which is a material property.

$$R = \rho \frac{L}{A}$$

Where:

R = Resistance

ρ = Resistivity

L = Length of wire

A = Cross sectional area

As the temperature increases, the resistivity and the resistance increases. If δT is small then the resistivity is:

$$\rho_T = \rho_0(1 + \alpha(T - T_0))$$

Where:

ρ_T = Final resistivity

ρ_0 = Resistivity at T_0

T_0 = Start temperature

α = Coefficient of resistivity

If you multiply both sides by $\frac{L}{A}$ you get

$$R_T = R_0(1 + \alpha(T - T_0))$$

Where:

R_T = Final resistance

R_0 = Resistance at T_0

T_0 = Start temperature

α = Coefficient of resistivity

The definition of resistance (Ohms law) is the ratio between the voltage drop (V) across it and the current (I) through it

$$R = \frac{V}{I}$$

Ohms law states the “the current through an ohmic conductor is directly proportional to the p.d. across it, provided there is no change in the physical condition (such as temperature)”

6.3 DC Circuits

Direct current circuits are circuits in which the current only flows in a single direction. For any combination of ohmic resistors you can find a single equivalent resistor to replace them. Resistors can be arranged either in series or in parallel, and these both have different equations for finding the total resistance.

For resistors in series the total resistance is

$$R_T = R_1 + R_2 + \dots$$

For resistors in parallel, the total resistance is

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$