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ONLINE LESSON O LEVEL (UCE)

DATE: **27 th April 2026**

TIME: 7 p.m - 9 p.m

SUBJECT: PHYSICS

ELEMENT OF CONSTRUCT : **Mechanics and heat properties**

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TOPICS

- Measurements in Physics
- States of Matter
- Effects of forces
- Work, Energy, and Power
- Turning Effect of Forces, Center of Gravity, and Stability
- Pressure in solids and fluids
- Mechanical properties of Materials and Hooke's law
- Linear and non-linear motion
- Temperature Measurements
- Heat Transfer
- Expansion of solids, liquids, and gases
- Heat quantities and vapours

Item 1

A group of students visited a large water reservoir dam during a field trip. They noticed that the base of the dam wall was significantly thicker and wider than the top part. The engineer on-site explained that this design is a safety requirement due to the nature of the fluid it holds. Later that day, the students visited a construction site where workers were using long steel rods to reinforce concrete pillars. The engineer provided the following data for one steel rod: it has a length of 4.0 m, a cross-sectional area of 2.0×10^{-4} m², and it extends by 0.5 mm when a load of 2.5×10^{4} N is suspended from it.

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On their way back, the students stopped at a lakeside park. They noticed that as the sun began to set, a refreshing breeze started blowing from the lake toward the land. One student remarked that this breeze is not just pleasant but is actually used in various traditional and modern technologies.

Hint:

Steel rods are considered high-quality and safe for construction if their Young's Modulus (ratio of stress to strain) is at least 2.0×10^{11} Nm^{-2}.

Task:

(a) Explain to the students why the dam wall must be built thicker at the bottom than at the top, referring to the relationship between liquid pressure and depth.

(b) Determine whether the steel rods at the construction site are of "high quality" (Show your working clearly).

(c) Identify the breeze the students experienced at the lake and explain two practical applications of such atmospheric movements in real life.

Response to item 1

(a) Relationship Between Liquid Pressure and Depth

The design of the dam wall is a direct application of the physics of fluid pressure:

Pressure Increases with Depth: According to the formula for fluid pressure ($P = h\rho g$), the pressure exerted by water increases linearly with its depth (h).

Force at the Base: Because the water is deepest at the bottom of the dam, the horizontal force exerted by the water against the wall is greatest at the base.

Structural Stability: The wall is built thicker and wider at the bottom to withstand this immense pressure and provide a wider base of support, ensuring the dam does not crack, slide, or tip over under the weight of the reservoir.

(b) Determining Steel Quality (Young's Modulus)

To determine if the steel is of "high quality," we must calculate the Young's Modulus (Y) and compare it to the required threshold of 2.0 x 10^{11} Nm^{-2}

Identify Given Values:

Force (F): 2.5 x 10^4 N

Area (A): 2.0 x 10^{-4} m^2

Original Length (L): 4.0 m

Extension (e): 0.5 mm = 5.0 x 10^{-4} m

Calculate Tensile Stress:

$$Stress = \frac{F}{A} = \frac{2.5 \times 10^4 N}{2.0 \times 10^{-4} m^2} = 1.25 \times 10^8 Nm^{-2}$$

Calculate Tensile Strain:

$$Strain = \frac{e}{L} = \frac{5.0 \times 10^{-4} m}{4.0\ m} = 1.25 \times 10^{-4}$$

Calculate Young's Modulus (Y):

$$Y = \frac{Stress}{Strain} = \frac{1.25 \times 10^8}{1.25 \times 10^{-4}} = 1.0 \times 10^{12} Nm^{-2}$$

Conclusion: Since 1.0 × 10^{12} Nm^{-2} is significantly greater than the required 2.0 × 10^{11} Nm^{-2}, the steel rods are of high quality and safe for use in the building.

(c) Lake Breeze and Practical Applications

The breeze described is a Sea Breeze (or Lake Breeze), which occurs when the land heats up faster than the water during the day.

Identification: As the sun sets, the land begins to cool, but the water retains heat longer. However, the scenario describes a breeze blowing from the lake toward the land, which typically happens during the day or early evening when the air over the land is warmer (lower pressure) than the air over the water (higher pressure).

Two Practical Applications:

Natural Ventilation and Cooling: Architects design coastal and lakeside buildings with large windows facing the water to utilize these breezes for natural air conditioning, reducing the need for electric fans or AC.

Sailing and Fishing: Traditional fishermen use these predictable wind patterns to navigate their boats. They use the land breeze to go out into the lake at night/early morning and the sea/lake breeze to return to the shore in the afternoon.

Item 2

Living in an area where morning temperatures can be quite low, Sarah runs a small “Healthy Start” breakfast stall. Every morning, she must prepare 15 liters of fresh lemon ginger tea to serve her customers by 6:30 a.m. On a particularly cold morning, Sarah discovers that her water supply in the storage tank had partially frozen overnight.

To meet her deadline, she fetches 12 kg of ice at -5°C from the tank and places it into a large copper boiler with a mass of 4.5 kg. She uses an electric immersion heater rated at 3.5 kW to melt the ice and bring it to a boil. However, Sarah is aware that her old copper boiler is not perfectly insulated, and she estimates that 15% of the heat energy supplied by the heater is lost to the surrounding environment.

Hint:

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- Specific heat capacity of copper = 390 J $kg^{-1}K^{-1}$
- Specific heat capacity of ice = 2,100 J $kg^{-1}K^{1}$
- Specific heat capacity of water = 4,200 J $kg^{-1}K^{-1}$
- Specific latent heat of fusion of ice = 336,000Jkg^{-1}
- Boiling point of water = 100°C
- Melting point of ice = 0°C

Task:

Using the principle of conservation of energy, calculate the total amount of thermal energy required to:

i).Raise the temperature of the ice and the boiler from -5°C to 0°C}.

ii).Melt all the ice into water at 0°C.

iii).Heat the resulting water and the boiler from 0°C to the boiling point.

(b) Determine the actual time (in minutes) it will take to boil the tea, taking into account the energy lost to the surroundings.

c).If Sarah started the heating process at 5:45 a.m., will she be ready to serve her customers by 6:30 a.m.? Justify your answer.

d).Suggest two practical ways Sarah could improve the efficiency of this process to save on electricity costs and time.

Response to item 2

a)i)Phase 1: Warming the Ice and the Boiler (-5°C to 0°C)

Both the 12 kg of ice and the 4.5 kg copper boiler must be warmed to the melting point

Q1= (mice x cice x Δθ)+ (mboiler x ccopper x Δθ)

Q1 = (12 x 2,100 x 5) + (4.5 x 390 x 5)

Q1 = 126,000 + 8,775

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Q1=134,775 J

Phase 2: Melting the Ice (0°C Ice to 0°C Water)

Only the ice requires energy for this phase change (latent heat).

Q2 = mice x Lf

Q2 = 12 x 336,000

Q2 = 4,032,000 J

Phase 3: Boiling the Water and the Boiler (0°C to 100°C)

Now we have 12 kg of liquid water and the 4.5 kg boiler being heated to the boiling point.

Q3 = (mwater x cwater x Δθ) + (mboiler x ccopper x Δθ)

Q3= (12 x 4,200 z 100) + (4.5 x 390 x 100)

Q3 = 5,040,000 + 175,500

Q3= 5,215,500 J

Determining the Actual Time Taken

The heater is rated at 3.5 kW (3,500 J/s), but 15% of this energy is lost. Therefore, the Useful Power (Pu) is 85% of the total.

Pu = 3,500 x 0.85

= 2,975 W

Now, calculate time (t):

$$\boldsymbol{T} = \frac{\boldsymbol{Qtotal}}{\boldsymbol{Pu}}$$

$$\boldsymbol{t} = \frac{\mathbf{9,382,275}}{\mathbf{2,975}} = \mathbf{3,153.7}\boldsymbol{s}$$

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In minutes: 3,153.7 ÷ 60 = 52.56minutes

c).Time Management Justification

Start Time: 5:45 a.m.

Time Needed: 53 minutes (rounding up for safety).

Estimated Finish Time: 6:38 a.m.

Verdict: No, Sarah will not be ready. She will be approximately 8 minutes late for her 6:30 a.m. deadline.

d).Practical Improvements for Efficiency

Insulation (Lagging): Sarah should wrap the copper boiler in an insulating material like glass wool or even a thick dry cloth. This reduces the 15% heat loss to the surroundings, ensuring more energy goes directly into the water.

Use of a Tight-Fitting Lid: By keeping the boiler tightly covered, she reduces heat loss through evaporation and convection. This traps the steam and internal energy, significantly shortening the time to reach the boiling point.

Pre-heating/Indoor Storage: If Sarah stores her water tank indoors or in a slightly warmer area overnight to prevent it from reaching -5°C, she would eliminate the energy-heavy Phase 1 and Phase 2 entirely.

Item 2

A group of scouts went camping in a hilly area. They needed to fetch water from a deep valley. They noticed that when they used a long plastic pipe to siphon water from a higher tank to a lower bucket, the water flowed quickly. However, when they tried to use the same pipe to move water between two buckets at the exact same height, the water would not flow.

In the evening, they sat around a campfire. One scout noticed that even though they were sitting to the side of the fire, they could feel the heat intensely, but when a wooden board was placed between them and the fire, the heat vanished instantly.

Task:

(a) Explain the conditions necessary for a siphon to work and why it failed to move water between the two buckets at the same height.

(b) Identify the primary method of heat transfer that allowed the scouts to feel the heat from the side of the fire.

(c) Explain why the wooden board was able to block the heat, and suggest a material that would be even more effective than wood for making a heat shield.

Item 3

A medical NGO is delivering temperature-sensitive vaccines to a remote health center in a semi-arid region of Northern Uganda. To ensure the vaccines remain effective, they must be stored in a specialized refrigerator between 2°C and 8°C

Upon arrival, the health officer discovers that the digital thermometer for the refrigerator is broken. He decides to calibrate a spare, ungraduated mercury-in-glass thermometer to monitor the storage temperature.

To calibrate it, he places the thermometer in pure melting ice and marks the mercury level as L0 = 5cm. He then places it in steam above boiling water (at standard atmospheric pressure) and marks the level as L100 = 25cm.

The Task:

As a physics consultant assisting the health center, provide a technical assessment of the following:

(a) Fundamental Interval: Determine the length of the fundamental interval of this thermometer and explain what a “fixed point” is in thermometry.

(b) Temperature Calculation: When the thermometer is placed inside the vaccine refrigerator, the mercury level stands at 6.2cm. Calculate the temperature of the refrigerator. Is it safe for the vaccines?

c). Scale Conversion: Convert the refrigerator’s temperature (from part b) into Kelvin (K). Why is the Kelvin scale often preferred in scientific research over the Celsius scale?

(d) Design & Sensitivity: The NGO wants a more sensitive thermometer to detect even smaller changes in temperature. Suggest two physical changes that could be made to the design of this mercury thermometer to increase its sensitivity.

e).Material Choice: If the NGO were to send vaccines to a region where temperatures drop to -50°C, explain why this mercury thermometer would be useless and suggest an alternative liquid that could be used.

Response to item 3

(a) Siphon Conditions

A siphon requires two things to work:

- The pipe must be completely filled with the liquid (primed) to remove air.

The outlet must be lower than the surface of the liquid in the source tank.

It failed between the two buckets because there was no pressure difference (head) to drive the flow; gravity needs that height drop to pull the liquid column down.

(b) Primary Heat Transfer

The method is Radiation (specifically Infrared Radiation). Unlike Convection (which carries heat upwards), Radiation travels in straight lines in all directions and does not require a medium (like air) to move.

(c) The Wooden Board & Better Materials

Wood is a poor conductor and is opaque to thermal radiation, so it blocks the "line of sight" of the heat waves. An even better material would be a shiny metallic surface (like aluminum foil), which reflects the radiation away rather than absorbing it.