Department of Mechanical Engineering
Indian Institute of Technology New Delhi
II Semester -- 2022 – 2023

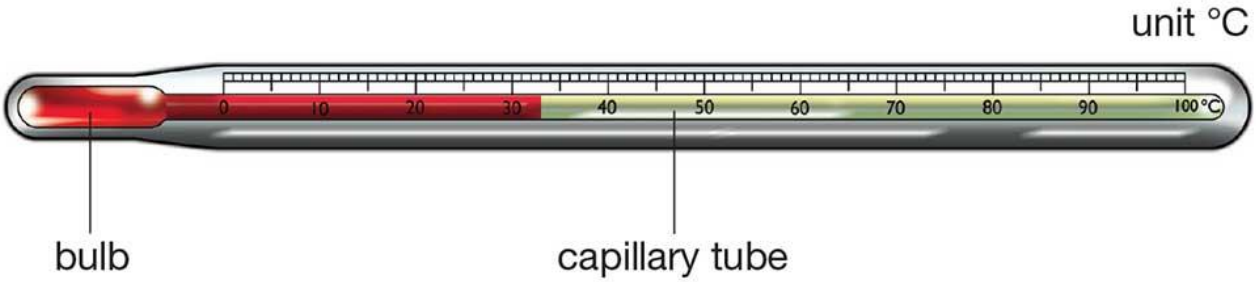
MCL142 Thermal Science for Electrical Engineers

Problem Set 1: Analysis of Zeroth Law

Problem 1: Identify few important electrical and electronics devices, which need to follow Zeroth Law of thermodynamics (directly or indirectly) for safe and reliable operation.

Problem 2: Identify few instruments used electrical and electronics, which need to follow mechanical equilibrium for accurate measurement of system properties.

Problem 3: Prove that ***Zeroth law*** of thermodynamics leads to design and selection of a thermometer with an appropriate value of time constant for each application.



Two thermometers using mercury and alcohol having same diameter of capillary tube (0.5mm) and same amount of increase liquid column (100mm increase in liquid column for an increase in temperature of 40°C) are considered for study.

The bulb length is equal to four times the bulb diameter.

Following table shows the properties of mercury & alcohol.

Material	Coefficient of Volumetric Thermal Expansion γ	Density at 0°*C*	Specific heat
Mercury	180×10^{-6} per°C	13594 kg/m^3	0.14 kJ/kg°C
Alcohol	1120×10^{-6} per°C	789 kg/m^3	2.4 kJ/kg°C

These two thermometers are suddenly immersed in a system with value of heat transfer coefficient**, U= 400 W/m^2°C (**proportionality constant in Newton's law of cooling**)**.

Carryout appropriate calculations and select a thermometer which demands less time to measure temperature of a system.

Problem 4: Table 1 shows properties of few materials, used for fabrication of temperature sensors.

Table 1

Material	Composition	Density, kg/m^3	Specific heat capacity, J/kgK	Heat conductivity, W/mK	Specific resistance, Ωmm^2/m
Copper	99% Cu	8954	383	386	0.017
Konstantan	60% Cu 40% Ni	8922	410	22.7	0.488
Iron	99% Fe	7897	452	73	0.119
Nickel chrome	90% Ni 10% Cr	8666	444	17.5	0.716
Nickel (L-nickel)	99% Ni	8906	446	46	0.268
Inconel	76% Ni 15% Cr 8% Fe	8510	461	17.5	
Chrom-nickel steel	71% Fe 18% Cr 8% Ni	7817	460	16.3	

Table 2 shows the values of Constant defined in Newton's Law of cooling (W/m^2K) and known as heat transfer coefficient in the field of Heat Transfer.

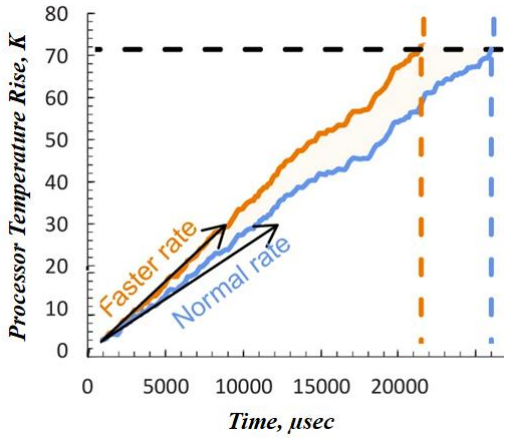
Table 2:

Medium	Speed, m/s	Diameter, mm							
		0.25	0.5	1.0	1.5	2.0	3.0	4.5	6.0
Water	0.4	29 500	20 700	14 600	11 900	10 300	8 400	6 860	5 940
	0.2	21 100	14 700	10 300	8 430	7 290	5 940	4 850	4 200
Air	2	327	224	155	125	108	87	71	61
	1	242	163	112	90	77	63	51	44

Above table proves that the value of heat transfer coefficient can be varied by changing the type and speed of fluid.

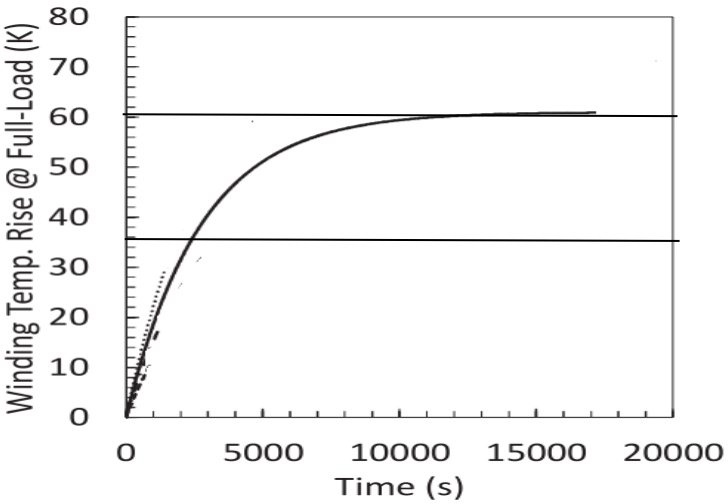
Solve following problems using the concepts learnt in Zeroth Law of Thermodynamics:

a) A CPU is in need of a sensor to measure diabatic condition with an accuracy of 98%, with in 1 second. Select suitable properties listed in above tables and determine the volume of sensor for air as cooling medium.
b) Average temperature of a Multi-core processor is linearly with time as shown below:



Is it possible to measure the processor temperature at 20000 µsec, with an error of 0.2°C? If yes, given the value of time constant required for the sensor. If not estimate the minimum error possible with above sensor and its time constant.

c) Temporal evolution of local temperature in the rotor of a motor is shown below.



Approximate the shape of above plot to get an expression for temperature –time equation followed by a temperature sensor with time constant, τ_C. Also estimate the value of time constant to measure the steady state temperature of the rotor with an error of 0.5 K.