

**Al-Mustaqbal University / College of Engineering & Technology**

**Department (Communications Technologies Engineering)**

**Class (First)**

**Subject (dc electric circuit) / Code**

**Lecturer (M.Sc. Salwan Saud hatif )**

**1st term – Lecture No. & Lecture Name (Lec2 conductance and effect temperature on resistance and resistivity )**

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**Electrical Technology**

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## Conductance and Conductivity

Conductance (*G*) is reciprocal of resistance**\***. Whereas resistance of a conductor measures the ***opposition*** which it offers to the flow of current, the conductance measures the ***inducement*** which it offers to its flow.

*l*

 *l*

1 . *A*

From Eq. **(*i*)** of Art. 1.6, *R* =  *l*

*A*

or *G*   *A*

where  is called the ***conductivity* or *specific conductance*** of a conductor. The unit of conductance

is siemens (S). Earlier, this unit was called mho.

It is seen from the above equation that the conductivity of a material is given by

 = *G l*  *G* siemens  *l* metre  *G l* siemens/metre

*A*

*A* metre2

*A*

Hence, the unit of conductivity is siemens/metre (S/m).

## Effect of Temperature on Resistance

The effect of rise in temperature is :

* + 1. to ***increase*** the resistance of pure metals. The increase is large and fairly regular for normal

ranges of temperature.

The temperature/resistance graph is a straight line (Fig. 1.6). As would be presently clarified, metals have a positive temperature co-efficient of resistance.

* + 1. to ***increase*** the resistance of alloys, though in their case, the increase is relatively small and irregular. For some high-resistance alloys like Eureka (60% Cu and 40% Ni) and manganin, the increase in resistance is (or can be made) negligible over a considerable range of temperature.
		2. to ***decrease*** the resistance of electrolytes, insulators (such as paper, rubber, glass, mica etc.) and partial conductors such as carbon. Hence, insulators are said to possess a ***negative*** temperature-coefficient of resistance.

## Temperature Coefficient of Resistance

Let a metallic conductor having a resistance of *R*0 at 0°C be heated of *t*°C and let its resistance at this temperature be *Rt*. Then, considering normal ranges of temperature, it is found that the increase in resistance  *R* = *Rt* *R*0 depends

* + 1. directly on its initial resistance
		2. directly on the rise in temperature
		3. on the nature of the material of the conductor.

or *Rt*  *R*0  *R*  *t* or *Rt* *R*0 =  *R*0 *t* ...**(*i*)** where  (alpha) is a constant and is known as the *temperature coefficient of resistance* of the conduc- tor.

Rearranging Eq. **(*i*)**, we get  =

*Rt*  *R*0    *R R*0  *t R*0  *t*

If *R*0 = 1 , *t* = 1°C, then  =  *R* = *Rt* *R*0

Hence, the temperature-coefficient of a material may be defined as :

***the increase in resistance per ohm original resistance per °C rise in temperature.***

From Eq. **(*i*)**, we find that *Rt* = *R*0 (1 +  *t*) ...**(*ii*)**

**\*** In a.c. circuits, it has a slightly different meaning.

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# Conductance, Variations of Resistivity with Temperature

It should be remembered that the above equation holds good for both rise as well as fall in temperature. As tem- perature of a conductor is decreased, its resistance is also decreased. In Fig.

1.6 is shown the temperature/resistance graph for copper and is practically a straight line. If this line is extended backwards, it would cut the tempera- ture axis at a point where temperature is  234.5°C (a number quite easy to remember). It means that theoretically, the resistance of copper conductor will become zero at this point though as

### Electric Current and Ohm’s Law

**Fig. 1.6**

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 =

*t*

*R*0 (1  0*t*)  *R*0 

0

*R*0 (1  0 *t*)  *t* 1  0 *t*

  

*t*

0

1  0 *t*

shown by solid line, in practice, the curve departs from a straight line at very low temperatures. From the two similar triangles of Fig. 1.6 it is seen that :

 

*Rt*

*R*0 =

*t*  234.5  1   *t*

234.5 234.5



 *Rt*

= *R*0

1 

*t*

or *Rt* = *R*

0

234.5

(1 +  *t*) where  = 1/234.5 for copper.

## Value of  at Different Temperatures

So far we did not make any distinction between values of  at different temperatures. But it is found that value of  itself is not constant but depends on the initial temperature on which the increment in resistance is based. When the increment is based on the resistance measured at 0°C, then  has the value of 0. At any other initial temperature *t*°C, value of  is *t* and so on. It should be remembered that, for any conductor, 0 has the maximum value.

Suppose a conductor of resistance *R*0 at 0°C (point *A* in Fig. 1.7) is heated to *t*°C (point *B*). Its resistance *Rt* after heating is given by

(1 + *t*

=

0

*R*0

*Rt*

)

...**(*i*)**

is the temperature-coefficient at 0°C.

0

where

Now, suppose that we have a conductor of resistance *Rt* at temperature *t*°C. Let this conductor be ***cooled*** from *t*°C to 0°C. Obviously, now the initial point is *B* and the final point is *A*. The final resistance *R*0 is given in terms of the initial resistance by the following equation

 *R*0 = *Rt* [1 + *t* ( *t*)] = *Rt* (1 *t* . *t*) ...**(*ii*)**

From Eq. **(*ii*)** above, we have *t* =

*Rt*  *R*0 *Rt*  *t*

Substituting the value of *Rt* from Eq. (*i*), we get

...**(*iii*)**

**Fig. 1.7**

In general, let 1= tempt. coeff. at *t*1°C ; 2 = tempt. coeff. at *t*2°C. Then from Eq. **(*iii*)** above, we get

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 = 0 or 1  1  0 *t*1

1 1  0 *t*1 1 0

Similarly,

 1 = 1  0 *t*2

2 0

Subtracting one from the other, we get

 1  1 = (*t* *t* ) or 1 = 1 + (*t* *t* ) or  = 1

2 1

2 1 2 1 2 1

2 1/1  (*t*2  *t*1)

Values of  for copper at different temperatures are given in Table No. 1.3.

|  |
| --- |
| **Table 1.3. Different values of**  **for copper** |
| *Tempt. in °C* | 0 | 5 | 10 | 20 | 30 | 40 | 50 |
|  | 0.00427 | 0.00418 | 0.00409 | 0.00393 | 0.00378 | 0.00364 | 0.00352 |

In view of the dependence of  on the initial temperature, we may define ***the temperature***

***coefficient of resistance at a given temperature as the charge in resistance per ohm per degree centigrade change in temperature from the given temperature.***

In case *R*0 is not given, the relation between the known resistance *R*1 at *t*1°C and the unknown resistance *R*2 at *t*2°C can be found as follows :

*R*2 = *R*0 (1 + 0 *t*2) and *R*1 = *R*0 (1 + 0 *t*1)



*R*2 *R*1

=

2

1  0*t*1

1  0*t*

The above expression can be simplified by a little approximation as follows :

...**(*iv*)**

*R*2 = (1 +  *t* ) (1 +  *t* )1

*R*1 0 2 0 1

= (1 + 0 *t*2) (1 0 *t*1) [Using Binomial Theorem for expansion and

= 1 + 0 (*t*2  *t*1) neglecting squares and higher powers of (0 *t*1)]

  *R* = *R* [1 +  (*t*  *t* )] [Neglecting product ( 2*t t* )]

2 1 0 2 1 0 1 2

For more accurate calculations, Eq. **(*iv*)** should, however, be used.

## Variations of Resistivity with Temperature

Not only resistance but specific resistance or resistivity of metallic conductors also increases with rise in temperature and ***vice-versa***.

As seen from Fig. 1.8 the resistivities of metals vary linearly with temperature over a significant range of temperature-the variation becoming non-linear both at very high and at very low temperatures. Let, for any metallic conductor,

1 = resistivity at *t*1°C

**Fig. 1.8**

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2 = resistivity at *t*2°C

*m* = Slope of the linear part of the curve Then, it is seen that

*m* = 2  1

*t*2  *t*1

or 2

= 1

+ *m* (*t*2

*t*1) or 2 1 1

 *m* (*t*2

1

*t*1)

The ratio of *m/*1 is called the ***temperature coefficient of resistivity*** at temperature *t*1°C. It may be defined as numerically equal to the fractional change in 1 per °C change in the temperature from *t*1°C. It is almost equal to the temperature-coefficient of resistance 1. Hence, putting 1 = *m*/1, we get

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | 2 = | 1 [1 + 1 (*t*2 *t*1)] |  | or | simply as | *t* = | 0 (1 + 0 *t*) |  |
| **Note.** It has been found that although temperature is the most significant factor influencing the resistivityof metals, other factors like pressure and tension also affect resistivity to some extent. For most metals except lithium and calcium, increase in pressure leads to decrease in resistivity. However, resistivity increases withincrease in tension. |

**Example 1.11.** *A copper conductor has its specific resistance of 1.6*  *10**6 ohm-cm at 0°C and a resistance temperature coefficient of 1/254.5 per °C at 20°C. Find* ***(i)*** *the specific resistance and*

***(ii)*** *the resistance - temperature coefficient at 60°C.* **(F.Y. Engg. Pune Univ. Nov.)**

**Solution.**  =

 0 or

 1  0

   1 per °C

20 1  0  20 254.5 1  0  20

0 234.5

1. 60 = 0 (1 +   60) = 1.6  106 (1 + 60/234.5) = **2.01**  **10****6** **-cm**

0

1.  =

 0  1/ 234.5   **1 per°C**

60 1  0  60 1  (60 / 234.5)

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**Example 1.12.** *A platinum coil has a resistance of 3.146*  *at 40°C and 3.767*  *at 100°C. Find the resistance at 0°C and the temperature-coefficient of resistance at 40°C.*

**(Electrical Science-II, Allahabad Univ.)**

**Solution.** *R*100 = *R*0 (1 + 100 0) ...**(*i*)**

*R*40 = *R*0 (1 + 40 0) ...**(*ii*)**

3.767



3.146

1  100 0

= 1  40 0

or 0 = 0.00379 or 1/264 per°C

From **(*i*)**, we have 3.767 = *R*0 (1 + 100  0.00379)  *R*0 = **2.732** 

Now, 40 =

0

1  40 0

 0.00379 

1  40  0.00379

###  1 per°C 304

**Example 1.13.** *A potential difference of 250 V is applied to a field winding at 15°C and the current is 5 A. What will be the mean temperature of the winding when current has fallen to 3.91 A,*

*applied voltage being constant. Assume* 15 = *1/254.5.* **(Elect. Engg. Pune Univ.)**

**Solution.** Let *R*1 = winding resistance at 15°C; *R*2 = winding resistance at unknown mean tem- perature *t*2°C.

 *R*1 = 250/5 = 50 ; *R*2 = 250/3.91 = 63.94 

Now *R*2 = *R*1 [1 + 15 (*t*2  *t*1)]    50 1  1 (*t*2  15)

 *t*2 = **86°C**

 254.5 

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**Example 1.14.** *Two coils connected in series have resistances of 600*  *and 300*  *with tempt. coeff. of 0.1% and 0.4% respectively at 20°C. Find the resistance of the combination at a tempt. of 50°C. What is the effective tempt. coeff. of combination ?*

**Solution.** Resistance of 600  resistor at 50°C is = 600 [1 + 0.001 (50 20)] = 618 

Similarly, resistance of 300  resistor at 50°C is = 300 [1 + 0.004 (50 20)] = 336 

Hence, total resistance of combination at 50°C is = 618 + 336 = **954** 

Let  = resistance-temperature coefficient at 20°C Now, combination resistance at 20°C = 900  Combination resistance at 50°C = 954 

 954 = 900 [ 1 +  (50  20)]   = **0.002**

**Example 1.15.** *Two wires A and B are connected in series at 0°C and resistance of B is 3.5 times that of A. The resistance temperature coefficient of A is 0.4% and that of the combination is 0.1%. Find the resistance temperature coefficient of B.* **(Elect. Technology, Hyderabad Univ.)**

**Solution.** A simple technique which gives quick results in such questions is illustrated by the diagram of Fig. 1.9. It is seen that *RB*/*RA* = 0.003/(0.001 )

or 3.5 = 0.003/(0.001  )

or  = 0.000143°C1 or **0.0143 %**

**Fig. 1.9**

**Example 1.16.** *Two materials A and B have resistance temperature coefficients of 0.004 and 0.0004 respectively at a given temperature. In what proportion must A and B be joined in series to pro- duce a circuit having a temperature coefficient of*

*0.001 ?*

**(Elect. Technology, Indore Univ.)**

**Solution.** Let *RA* and *RB* be the resistances of the two wires of materials *A* and *B* which are to be connected in series. Their ratio may be found by the simple technique shown in Fig. 1.10.

**Fig. 1.10**

*RB*

*RA*

Hence, *RB* must be **5 times *RA.***

= 0.003  5 0.0006

**Example 1.17.** *A resistor of 80*  *resistance, having a temperature coefficient of 0.0021 per degree C is to be constructed. Wires of two materials of suitable*

*cross-sectional area are available. For material A, the resistance is 80 ohm per 100 metres and the temperature coefficient is 0.003 per degree C. For material B, the corresponding figures are 60 ohm per metre and 0.0015 per degree C. Calculate suitable lengths of wires of materials A and B to be connected in series to construct the required resistor. All data are referred to the same temperature.*

**Solution.** Let *Ra* and *Rb* be the resistances of suitable lengths of materials *A* and *B* respectively which when joined in series will have a combined temperature coeff. of 0.0021. Hence, combination resistance at any given temperature is (*Ra* + *Rb*). Suppose we heat these materials through *t*°C.

When heated, resistance of *A* increases from *Ra* to *Ra* (1 + 0.003 *t*). Similarly, resistance of *B*

increases from *Rb* to *Rb* (1 + 0.0015 *t*).

 combination resistance after being heated through *t*°C

= *Ra* (1 + 0.003 *t*) + *Rb* (1 + 0.0015 *t*)

The combination  being given, value of combination resistance can be also found directly as

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= (*Ra* + *Rb*) (1 + 0.0021 *t*)

 (*Ra* + *Rb*) (1 + 0.0021 *t*) = *Ra* (1 + 0.003 *t*) + *Rb* (1 + 0.0015 *t*)

*Rb*

Simplifying the above, we get *Ra*

= 3 2

...**(*i*)**

Now *Ra* + *Rb* = 80  ...**(*ii*)**

Substituting the value of *Rb* from **(*i*)** into **(*ii*)** we get

*Ra*  3 *Ra* = 80 or *R* = 32  and *R* = 48 

2

*a b*

If *La* and *Lb* are the required lengths in metres, then

*La* = (100/80)  32 = **40 m** and *Lb* = (100/60)  48 = **80 m**

**Example 1.18.** *A coil has a resistance of 18*  *when its mean temperature is 20°C and of 20*  *when its mean temperature is 50°C. Find its mean temperature rise when its resistance is 21*  *and the surrounding temperature is 15*° *C.* **(Elect. Technology, Allahabad Univ.)**

**Solution.** Let *R*0 be the resistance of the coil and 0 its tempt. coefficient at 0°C. Then, 18 = *R*0 (1 + 0  20) and 20 = *R*0 (1 + 50 0)

Dividing one by the other, we get

20

= 1  50 0

   1 per°C

18 1  20 0

0 250

If *t*°C is the temperature of the coil when its resistance is 21 , then,

21 = *R*0 (1 + *t*/250)

Dividing this equation by the above equation, we have

21 18

= *R*0 (1  *t*/250) ;

*R*0 (1  20 0)

*t* = 65°C; temp. rise = 65 15 = **50°C**

**Example 1.19.** *The coil of a relay takes a current of 0.12 A when it is at the room temperature of 15°C and connected across a 60-V supply. If the minimum operating current of the relay is 0.1 A, calculate the temperature above which the relay will fail to operate when connected to the same supply. Resistance-temperature coefficient of the coil material is 0.0043 per°C at 6°C.*

**Solution.** Resistance of the relay coil at 15°C is *R*15 = 60/0.12 = 500 

Let *t*°C be the temperature at which the minimum operating current of 0.1 A flows in the relay coil. Then, *R*1 = 60/0.1 = 600 

Now *R*15 = *R*0 (1 + 15 0) = *R*0 (1 + 15  0.0043) and *Rt* = *R*0 (1 + 0.0043 *t*)

 *Rt* = 1  0.0043 *t* or 600  1  0.0043 *t*  *t* = **65.4°C**

*R*15

1.0654 500 1.0645

If the temperature rises above this value, then due to increase in resistance, the relay coil will draw a current less than 0.1 A and, therefore, will fail to operate.

**Example 1.20.** *Two conductors, one of copper and the other of iron, are connected in parallel and carry equal currents at 25°C. What proportion of current will pass through each if the tempera- ture is raised to 100°C ? The temperature coefficients of resistance at 0°C are 0.0043/°C and 0.0063/*

*°C for copper and iron respectively.* **(Principles of Elect. Engg. Delhi Univ.)**

**Solution.** Since the copper and iron conductors carry equal currents at 25°C, their resistances are the same at that temperature. Let each be *R* ohm.

For copper, *R*100 = *R*1 = *R* [1 + 0.0043 (100  25)] = 1.3225 *R*

For iron, *R*100 = *R*2 = *R* [1 + 0.0063 (100  25)] = 1.4725 *R*

If *I* is the current at 100°C, then as per current divider rule, current in the copper conductor is

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*I*1 =

*I*2 =

*I R*2

*R*1  *R*2

*I R*2

*R*1  *R*2

 *I*  1.4725 *R*  0.5268 *I*

1.3225 *R*  1.4725 *R*

 *I* 1.3225 *R*  0.4732 *I*

2.795 *R*

Hence, copper conductor will carry **52.68%** of the total current and iron conductor will carry the balance *i.e.* **47.32%.**

**Example 1.21.** *The filament of a 240 V metal-filament lamp is to be constructed from a wire having a diameter of 0.02 mm and a resistivity at 20°C of 4.3* -*cm. If*  *= 0.005/°C, what length of filament is necessary if the lamp is to dissipate 60 watts at a filament tempt. of 2420°C ?*

**Solution.** Electric power generated = *I*2 *R* watts = *V*2/*R* watts

 *V*2/*R* = 60 or 2402/*R* = 60

Resistance at 2420°C *R*

2420

= 240  240  960 

60

Now *R*2420 = *R*20 [1 + (2420 20)  0.005]

or 960 = *R*20 (1 + 12)

 *R*20 = 960/13 

6

(0.002)2 2

Now 20 = 4.3  10 -cm and *A* = 4 cm

*A*  *R*20   (0.002)2  960 

 *l* =

20

4  13  4.3  106

### 54 cm

**Fig.1.11**

**Example 1.22.** *A semi-circular ring of copper has an inner radius 6 cm, radial thickness 3 cm and an axial thickness 4 cm. Find the resistance of the ring at 50°C between its two end-faces. Assume specific resistance of Cu at 20°C = 1.724*  *10**6 ohm-cm and resistance tempt. coeff. of Cu at 0°C = 0.0043/°C.*

**Solution.** The semi-circular ring is shown in Fig. 1.11. Mean radius of ring = (6 + 9)/2 = 7.5 cm Mean length between end faces = 7.5  cm = 23.56 cm

Now  = 0.0043/°C;  = 0.0043  0.00396

Cross-section of the ring

= 3  4 = 12 cm2

0

20

1  20  0.0043

50 = 20 [1 + 0 (50  20)]

= 1.724  106 (1 + 30  0.00396) = 1.93  106 -cm

*R*50 =

50  *l A*



1.93  106  23.56

12

 **3.79 × 10** 

**6**

**Tutorial Problems No. 1.2**

1. It is found that the resistance of a coil of wire increases from 40 ohm at 15°C to 50 ohm at 60°C. Calculate the resistance temperature coefficient at 0°C of the conductor material.

**[1/165 per °C] (*Elect. Technology, Indore Univ.*)**

1. A tungsten lamp filament has a temperature of 2,050°C and a resistance of 500  when taking normal working current. Calculate the resistance of the filament when it has a temperature of 25°C. Tem- perature coefficient at 0°C is 0.005/°C. **[50** **] (*Elect. Technology, Indore Univ.*)**

### Electric Current and Ohm’s Law

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1. An armature has a resistance of 0.2  at 150°C and the armature Cu loss is to be limited to 600 watts with a temperature rise of 55°C. If 0 for Cu is 0.0043/°C, what is the maximum current that can be passed through the armature ? **[50.8 A]**
2. A d.c. shunt motor after running for several hours on constant voltage mains of 400 V takes a field current of 1.6 A. If the temperature rise is known to be 40°C, what value of extra circuit resistance is required to adjust the field current to 1.6 A when starting from cold at 20°C ? Temperature coefficient

= 0.0043/°C at 20°C. **[36.69** **]**

1. In a test to determine the resistance of a single-core cable, an applied voltage of 2.5 V was necessary to produce a current of 2 A in it at 15°C.
	1. Calculate the cable resistance at 55°C if the temperature coefficient of resistance of copper at 0°C is 1/235 per°C.
	2. If the cable under working conditions carries a current of 10 A at this temperature, calculate the power dissipated in the cable. **[(*a*) 1.45**  **(*b*) 145 W]**
2. An electric radiator is required to dissipate 1 kW when connected to a 230 V supply. If the coils of the radiator are of wire 0.5 mm in diameter having resistivity of 60 -cm, calculate the necessary length of the wire. **[1732 cm]**
3. An electric heating element to dissipate 450 watts on 250 V mains is to be made from nichrome ribbon of width 1 mm and thickness 0.05 mm. Calculate the length of the ribbon required (the resistivity of nichrome is 110  108 -m). **[631 m]**
4. When burning normally, the temperature of the filament in a 230 V, 150 W gas-filled tungsten lamp is 2,750°C. Assuming a room temperature of 16°C, calculate (*a*) the normal current taken by the lamp

(*b*) the current taken at the moment of switching on. Temperature coefficient of tungsten is 0.0047

°C at 0°C. **[(*a*) 0.652 A (*b*) 8.45 A] (*Elect. Engg. Madras Univ.*)**

1. An aluminium wire 5 m long and 2 mm diameter is connected in parallel with a wire 3 m long. The total current is 4 A and that in the aluminium wire is 2.5 A. Find the diameter of the copper wire. The respective resistivities of copper and aluminium are 1.7 and 2.6 µ-m. **[0.97 mm]**
2. The field winding of d.c. motor connected across 230 V supply takes 1.15 A at room temp. of 20°C. After working for some hours the current falls to 0.26 A, the supply voltage remaining constant. Calculate the final working temperature of field winding. Resistance temperature coefficient of cop- per at 20°C is 1/254.5. **[70.4°C] (*Elect. Engg. Pune Univ.*)**
3. It is required to construct a resistance of 100  having a temperature coefficient of 0.001 per*°*C. Wires of two materials of suitable cross-sectional area are available. For material *A*, the resistance is 97  per 100 metres and for material *B*, the resistance is 40  per 100 metres. The temperature coefficient of resistance for material *A* is 0.003 per °C and for material *B* is 0.0005 per °C. Deter- mine suitable lengths of wires of materials *A* and *B*. **[A : 19.4 m, B : 200 m]**
4. The resistance of the shunt winding of a d.c. machine is measured before and after a run of several hours. The average values are 55 ohms and 63 ohms. Calculate the rise in temperature of the winding. (Temperature coefficient of resistance of copper is 0.00428 ohm per ohm per °C).

**[36°C] (*London Univ.*)**

1. A piece of resistance wire, 15.6 m long and of cross-sectional area 12 mm2 at a temperature of 0°C, passes a current of 7.9 A when connected to d.c. supply at 240 V. Calculate (*a*) resistivity of the wire

(*b*) the current which will flow when the temperature rises to 55°C. The temperature coefficient of the resistance wire is 0.00029 °C. **[(*a*) 23.37 µ****-m (*b*) 7.78 A] (*London Univ.*)**

1. A coil is connected to a constant d.c. supply of 100 V. At start, when it was at the room temperature of 25°C, it drew a current of 13 A. After sometime, its temperature was 70°C and the current reduced to 8.5 A. Find the current it will draw when its temperature increases further to 80°C. Also, find the temperature coefficient of resistance of the coil material at 25°C.

**[7.9 A; 0.01176°C****1] (*F.Y. Engg. Univ.*)**

1. The resistance of the filed coils with copper conductors of a dynamo is 120  at 25°C. After working for 6 hours on full load, the resistance of the coil increases to 140 . Calculate the mean temperature rise of the field coil. Take the temperature coefficient of the conductor material as 0.0042 at 0°C.

**[43.8°C] (*Elements of Elec. Engg. Banglore Univ.*)**

Conductance, Variations of Resistivity with Temperature