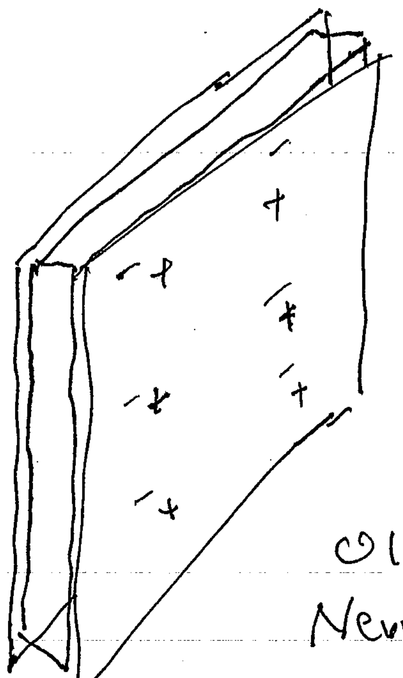
Lecture # 9

Dielectric Surface Charge



Insertion of a dielectric into plates of fixed charge, Q_0, reduces Voltage, V_0 to V_0/κ

Old Capacitance $C_0 = \frac{Q_0}{V_0}$

New Capacitance, C_d, on dielectric:

$$C_d = \frac{Q_0}{V_0/\kappa} = \kappa \frac{Q_0}{V_0} = \kappa C_0$$

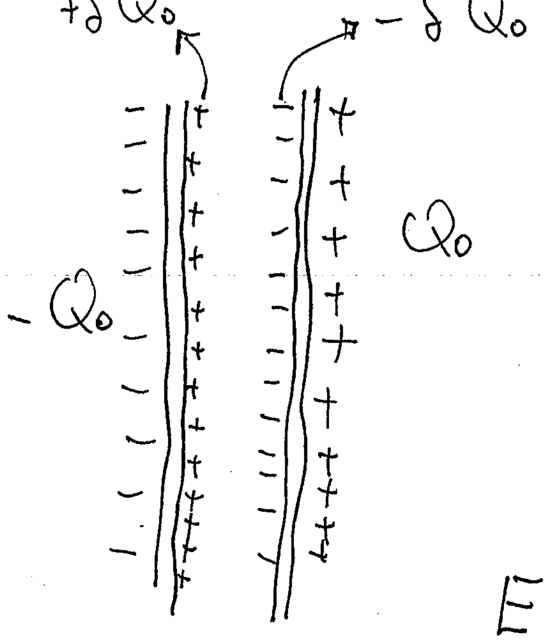
Why does voltage decrease with dielectric insertion?

(1) Charges move in dielectric to produce partially cancelling electric fields

(2) Ions are produced in electric field and they flow, to cancel the electric field

(3) Molecules polarize to form dipoles the produce partially cancelling surface charge

2.



What is δ?

Voltage across plate is $V = Ed = \frac{V_0}{\kappa}$

$$E = (Q_0 - \delta Q_0)/\epsilon_0 A$$

$$V = Ed = \underbrace{\frac{Q_0 d}{\epsilon_0 A}}_{= V_0}(1-\delta) = \frac{V_0}{\kappa}$$

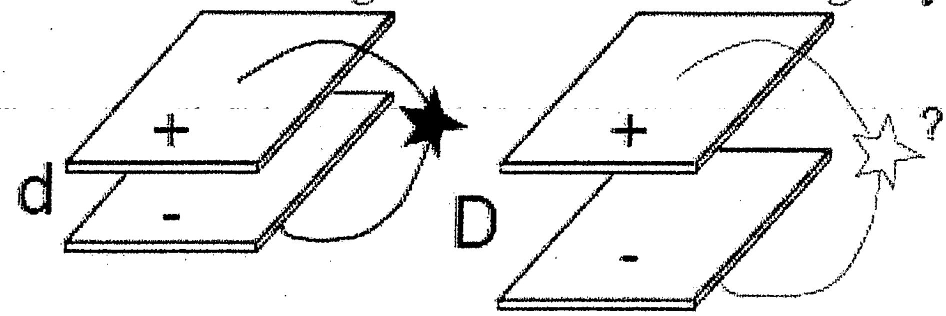
$$\therefore \quad V_0(1-\delta) = \frac{V_0}{\kappa}$$

$$\therefore \quad \boxed{\delta = 1 - \frac{1}{\kappa}}$$

The magnitude of induced charge is

$$\boxed{Q_{ind} = \left(1 - \frac{1}{\kappa}\right) Q_0}$$

The two isolated parallel plate capacitors below, one with plate separation d and the other with $D > d$, have the same plate area A and are given the same charge Q.



1

2

The energy in the spark produced by discharging the second capacitor is

1. less energetic than the discharge spark of the first capacitor.

2. more energetic than the discharge spark of the first capacitor.

3. the same as the discharge spark of the first capacitor.

Energy stored in Capacitor

$$U_E = \frac{QV}{2} = \frac{Q^2}{2C} = \frac{CV^2}{2}$$

(1) At fixed charge, smaller capacitors store more energy

(2) At fixed voltage, large capacitors store more energy

(3) Batteries & power plants produce fixed voltage, allowing large capacitors to store more energy than smaller capacitors

(4) The use of molecular polarization allows substantial increase of capacitance for the same device dimensions ($\varkappa \simeq 10$ fairly typical)

(no dielectric) $C_0 \rightarrow \varkappa C_0$ (with dielectric)

1) Motion of charges gives rise to currents

2) Mechanism in some ways similar to a rain drop falling to the ground

Question

How does a rain-drop fall to the ground

(1) By continually accelerating

(2) Falls at constant velocity

(3) Moves chaotically but on the average moves at constant velocity in direction of gravitational force

How does an electron in a metal move in the presence of an electric field?

(1) Moves with continual acceleration in the direction opposite electric field direction

(2) Moves at constant velocity directed opposite to electric field

(3) Moves chaotically but on average moves with constant velocity opposite to electric field

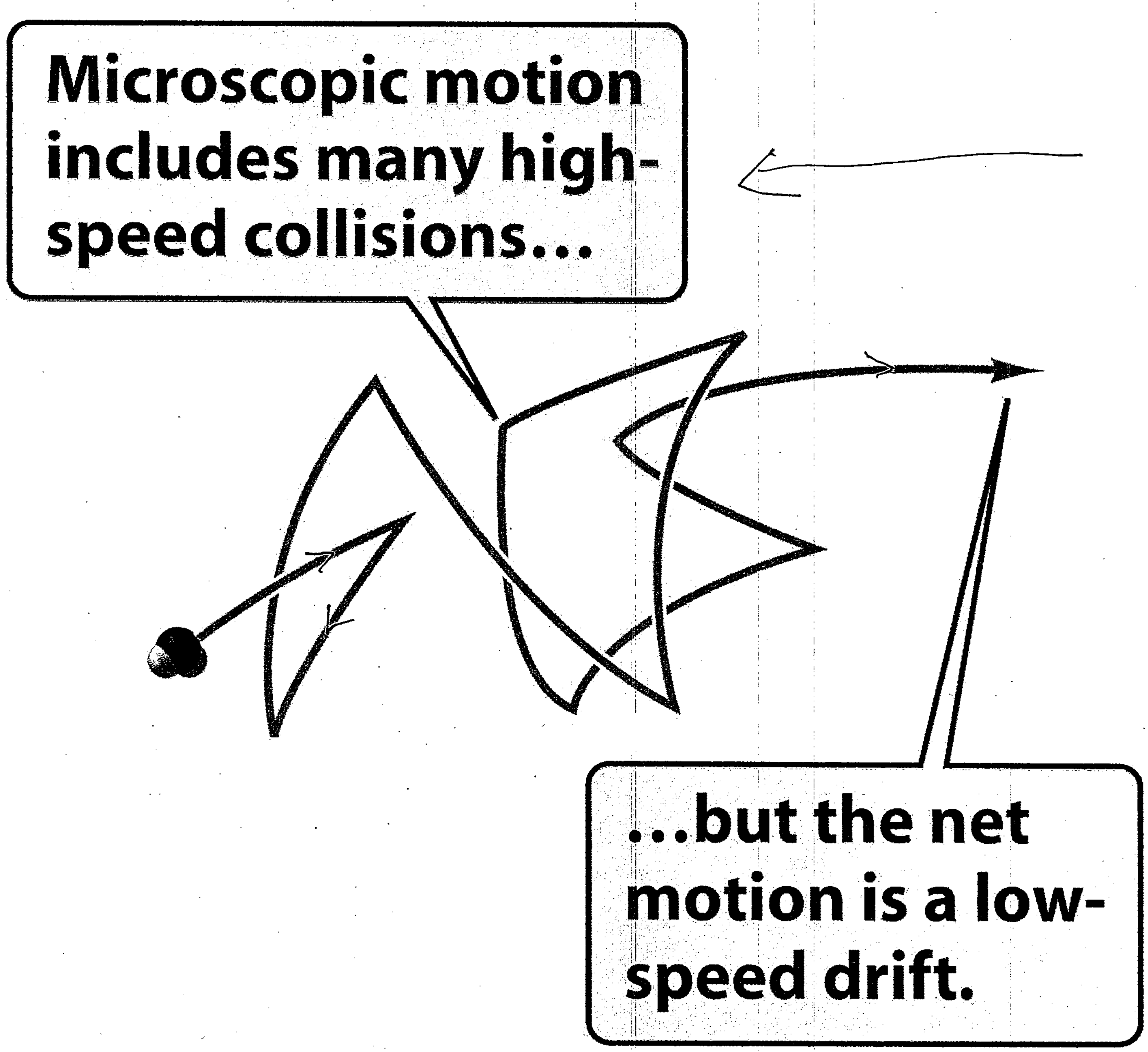


Figure 27-6 Physics for Engineers and Scientists 3/e

Resistivity, ρ, (a material's property at given temperature)

Atomistic model

particle (an electron) has charge q ($q = -e$ for electrons)

Electric force on electron is balanced by a viscous-force that is property of material

$$\vec{F}_e = q\vec{E} \quad , \quad \vec{F}_v = m\vec{V}/\tau$$

$\tau \equiv$ relaxation time (a material property)

$$\vec{F}_e = \vec{F}_v \; ; \quad \therefore \quad q\vec{E} = \frac{m\vec{V}}{\tau} \; ; \quad m \equiv \text{mass of charge carrier}$$

$$\vec{V} = q\frac{\vec{E}\tau}{m} \equiv \vec{V}_D$$

$N_c \equiv$ # of charge carriers per unit Volume

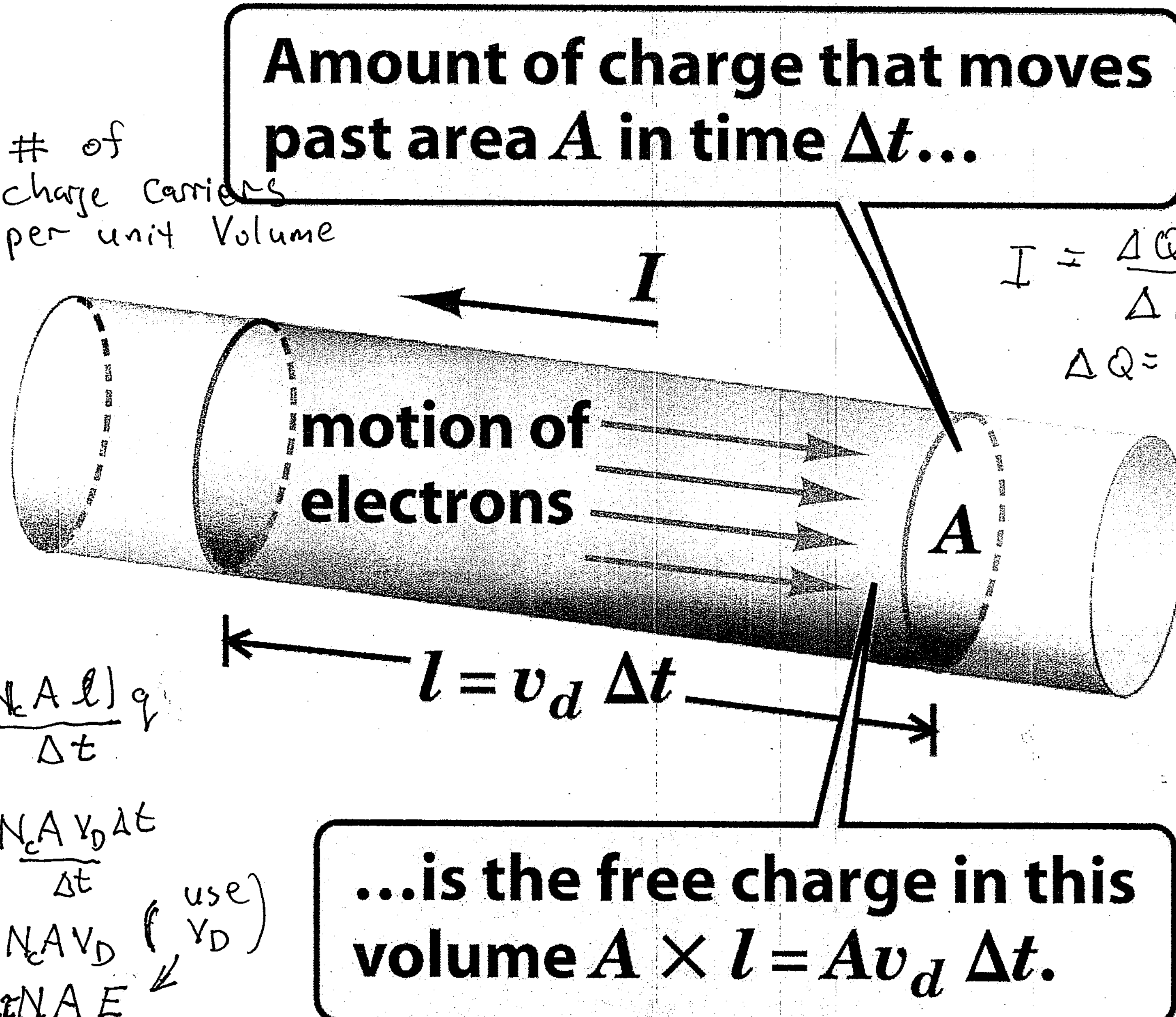


Figure 27-7 Physics for Engineers and Scientists 3/e

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

$$\Delta Q = e\,N_c\,(lA)$$

$$= e\,N_c\,(l\,v_d\,\Delta t)$$

$$v_D = \frac{e\tau E}{m}$$

$$I = \frac{(N_c A\, l)\,q}{\Delta t}$$

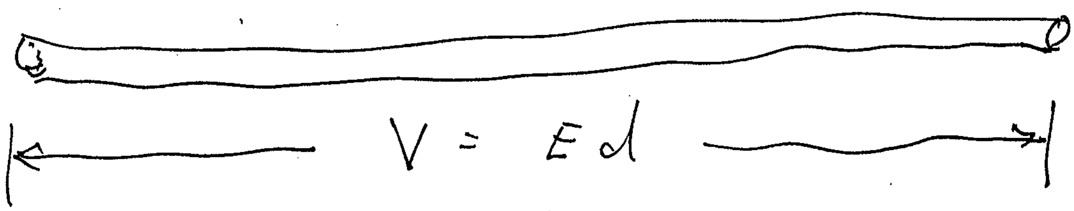
$$= \frac{N_c A\, v_D\,\Delta t}{\Delta t}$$

$$= N_c A\, v_D \quad (\text{use } v_D)$$

$$I = \frac{e\tau}{m} N_c A E$$

$$\therefore\ E = \frac{I}{A}\left(\frac{m}{e\tau N_c}\right) = \frac{I\rho}{A};\quad \rho = \text{resistivity}$$

$$E = \frac{I\rho}{A} \quad ; \quad \rho = \underbrace{\frac{m}{e\tau N_c}}_{\text{depends on material property}}$$



Voltage across resistor

$$V = Ed = I\left(\frac{\rho d}{A}\right) \equiv IR$$

Resistance : $R = \dfrac{\rho d}{A}$

$I = V/R \equiv$ Ohm's Law

Unit of Current $\equiv$ Amperes (A)

Unit of Resistance $\equiv$ Ohm (Ω)

Temperature dependence of resistive material

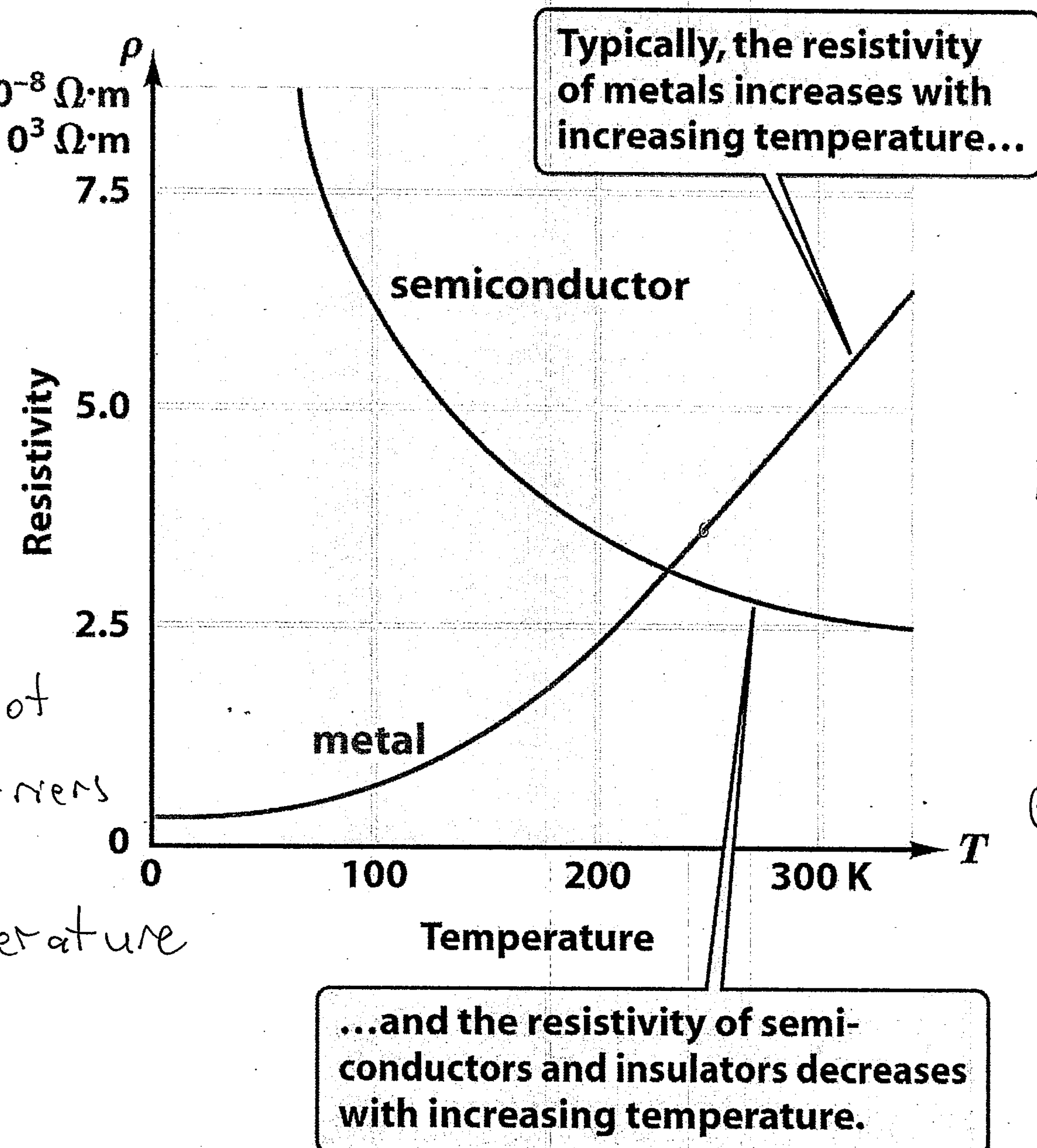


Figure 27-8 Physics for Engineers and Scientists 3/e

In semiconductor, the number of charged carriers increase with temperature

Metal

$$\frac{\partial \rho}{\partial T} = \alpha \equiv \text{roughly constant at room temperature}$$

$$\rho(T) \approx \rho(T_0) + \alpha(T - T_0)$$

Nature can do some strange things.

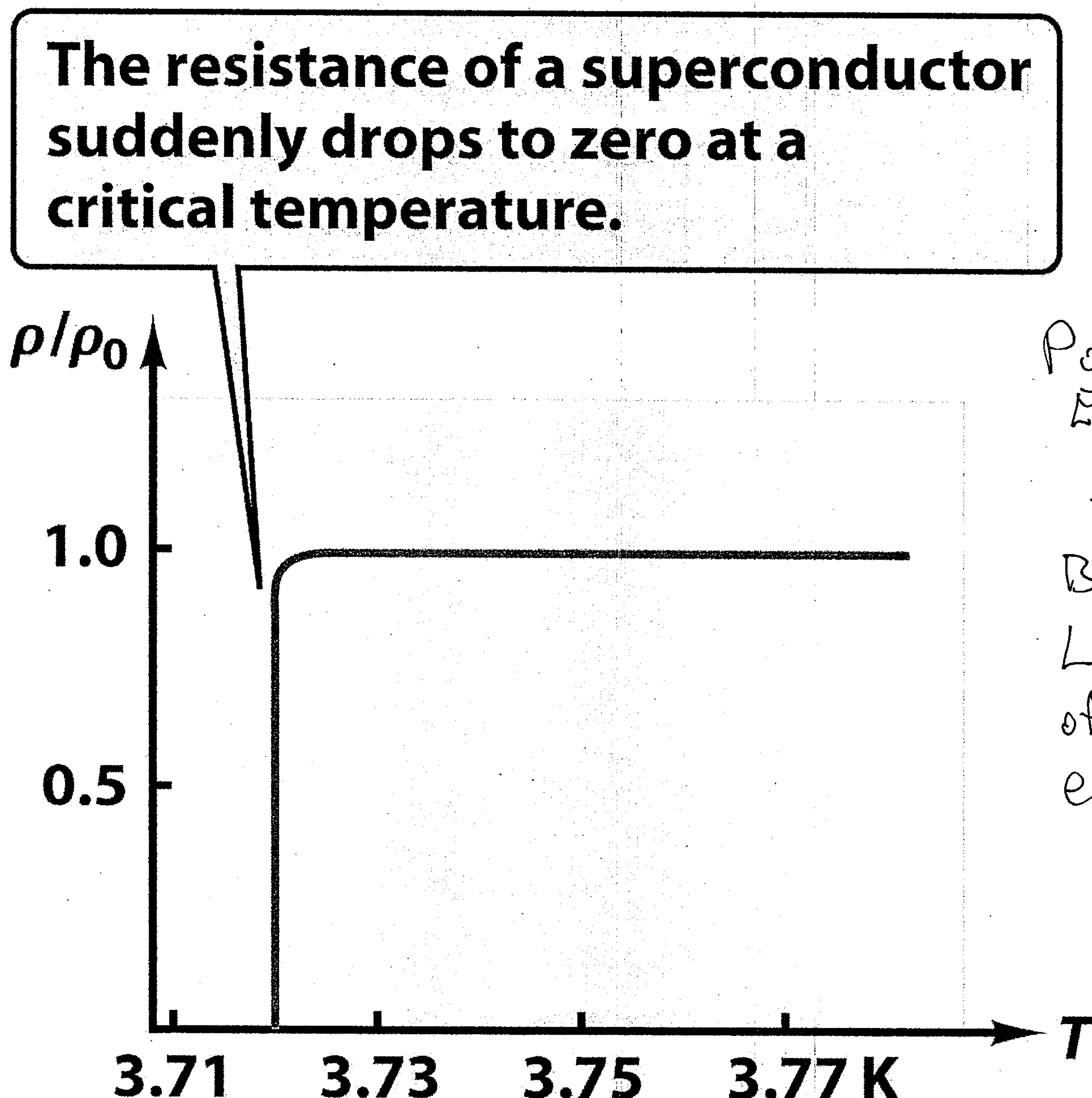


Figure 27-10 Physics for Engineers and Scientists 3/e

Power Engineer's Dream

Build Transmission Lines free of Resistive energy losses

Various currents nature and man make

TABLE 27.1 SOME CURRENTS

Lightning stroke (a)	10^4 A
High-tension power line (b)	10^3
Large transformer (c)	10^3
Large electromagnet	200
Starter motor of automobile (d)	100
Alternator of automobile	30
Fuse blows	30
Defibrillation treatment for heart	20
Air conditioner	12
Hair dryer	10
Ordinary lightbulb	1
Flashlight bulb	0.5
Lethal fibrillation of heart	0.1
Barely perceptible by skin	1×10^{-3}
Electronic calculator (e)	1×10^{-4}
Scanning tunneling microscope	1×10^{-12}

Table 27-1 Physics for Engineers and Scientists 3/e

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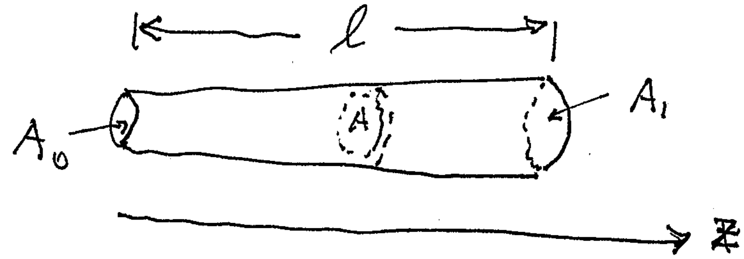
Find resistance through resistive object with non-uniform cross section

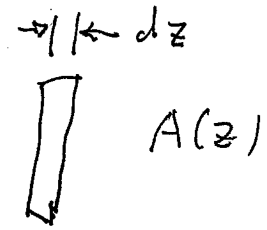
resistivity ρ



$$A(z) = A_0 + (A_1 - A_0)\, z/l$$

Current, I, is the same anywhere is object

I



Voltage drop across incremental slab ; $R(\Delta z) = \rho \Delta z / A(z)$

$$\Delta V = I \frac{\rho \Delta z}{A(z)} = \frac{I \rho \, \Delta z}{A_0 + (A_1 - A_0) z/l}$$

$$\frac{dV}{dz} = \frac{I \rho}{(A_1 - A_0)\left[\frac{A_0}{A_1 - A_0} + \frac{z}{l}\right]} = E$$

$$V = \int_0^l \frac{dV}{dz}\, dz = \frac{I\rho}{(A_1 - A_0)} \int_0^l \frac{dz}{\frac{A_0}{A_1 - A_0} + z/l} = \frac{I\rho l}{A_1 - A_0}\left(\ln\left(\frac{A_0}{A_1 - A_0} + \frac{z}{l}\right)\Big|_0^l \right)$$

$$= \frac{I \rho l}{A_1 - A_0} \ln\left(\frac{A_1}{A_0}\right) \equiv IR \; ; \quad \boxed{R = \frac{\rho l}{A_1 - A_0} \ln\left(\frac{A_1}{A_0}\right)}$$

	#
B	0
Br	1
R	2
O	3
Y	4
G	5
Bl	6
V	7
Gray	8
W	9
Gold	-
Ag	
None	

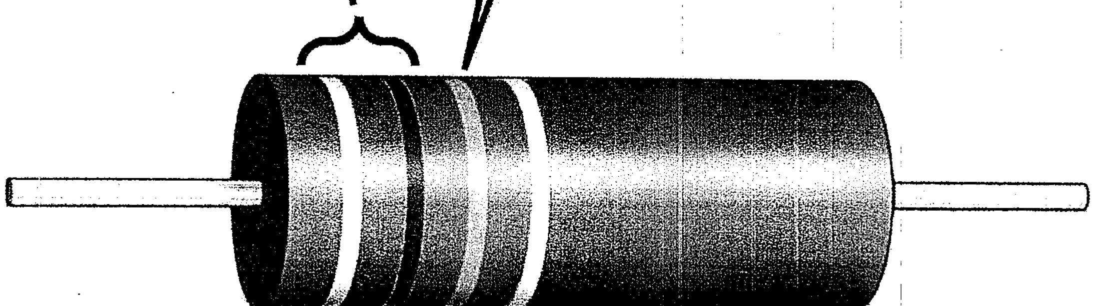


Figure 27-13 Physics for Engineers and Scientists 3/e

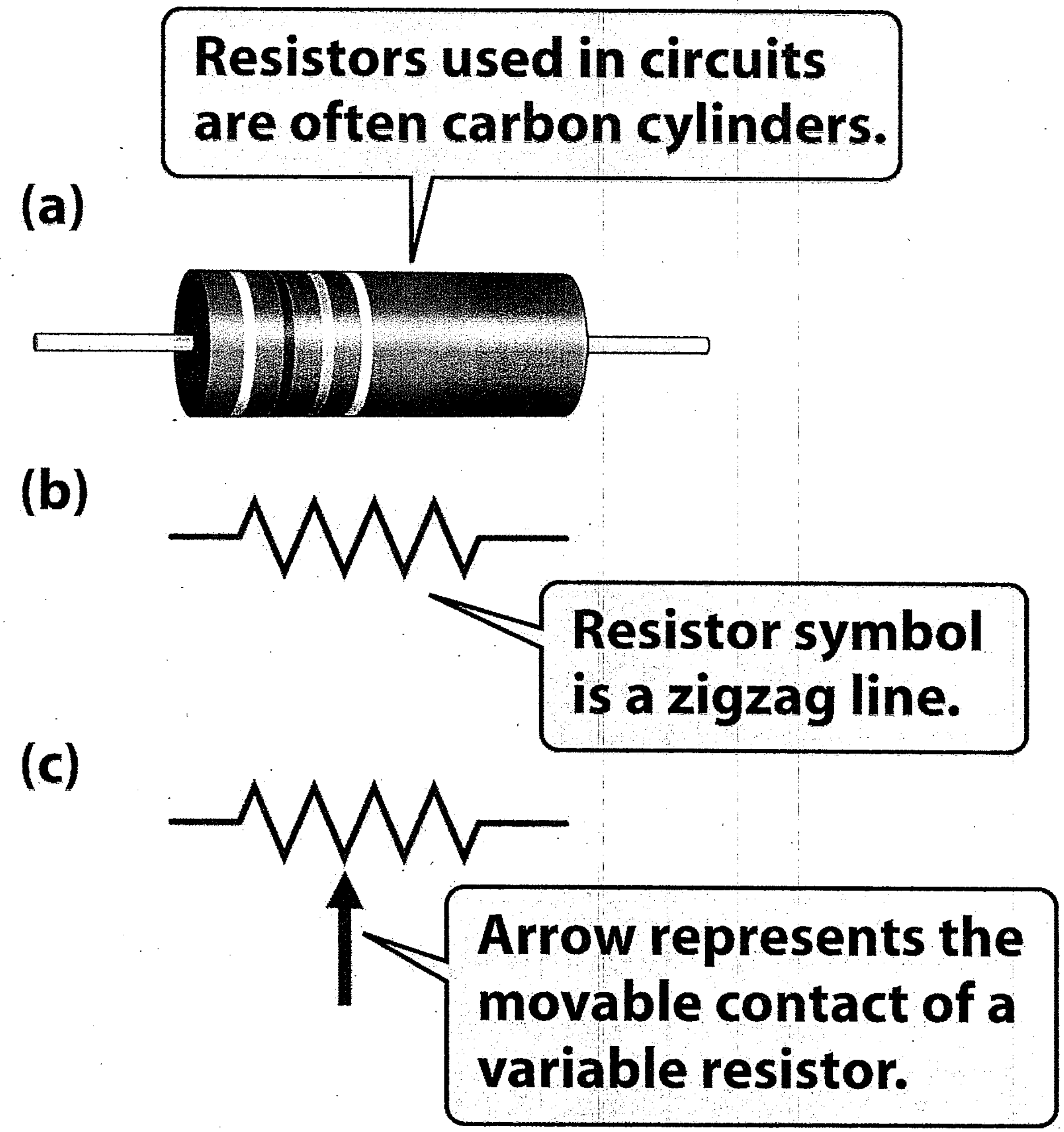


Figure 27-12 Physics for Engineers and Scientists 3/e