Electric Currents and Drift Velocity

Three motions associated with an electric current:

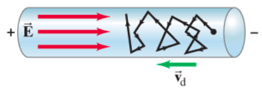


Figure 18–24

Propagation of $\vec{E}$ ____________
Random motion of electrons ____________
Drift of electrons _____________

37

What is resistance? (It's such a drag.)

When current flows the electrons bounce around and *slowly* drift against the current.

Not all the electrons drift – just the ones that are "free" (loosely bound in the atom).

38

The ability of a material to conduct electricity is related to the number of free electrons available per unit volume, n, and the average time between collisions, τ. The microscopic formula for the resistivity, ρ, is

$$\rho = \frac{m_e}{ne^2\tau}$$

where m_e and e are the mass and charge of the electron, respectively.

39

(20) If τ went up (longer time between collisions) would resistivity go up or down? ____________
(21) Makes sense?

____

(22) If n went up (larger density of free electrons) would resistivity go up or down? ____________
(23) Makes sense?

40 ____________________________________

(24) If m_e went up (larger electron mass) would resistivity go up or down? __________
(25) Makes sense?

____

(26) If e went up (larger electron charge) would resistivity go up or down? ____________
(27) Makes sense?

41 ________________________________

Such a drag

Channelling your inner $F = ma$, what does a constant F imply about whether
(28) a is constant? ___________
(29) v is constant? ______________

42

ADDITIONAL NOTES

(30) Channelling $E = -\Delta V/\Delta d$, what does a fixed potential difference, ΔV, across a fixed distance gap, Δd, tell you about whether the electric field, E, is constant or not? ______________

(31) Channelling $F = qE$, if E is constant, what is F, and therefore a and v? ______________

____

43

(32) From all this, what should applying a fixed potential difference to the ends of a conducting wire do *theoretically* to the free electrons in it?

____

(33) What does it actually do in practice?

____

(34) How come?

44

Ask him if it's a drag →

Collisions act like a frictional force proportional to speed.

$$F_{\text{const}} - kv = ma$$

Starting with $v = 0$, contemplate. . .

45

AC vs DC

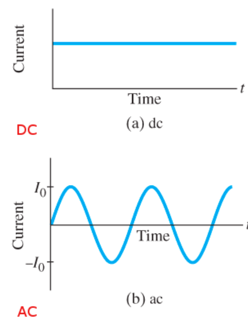


Figure 18–21

Direct Current flows in one direction.

Alternating Current goes back and forth.

46

Materials that obey Ohm's Law do so whether the current is DC or AC. Therefore, the voltage also goes back and forth in an AC current.

A common model is "sinusoidal:"

$$V = V_0\, sin\, 2\pi f t$$

where f is called the frequency of the current, and is measured in Hz.

47

(35) From the previous formula what are the highest and lowest possible voltages?

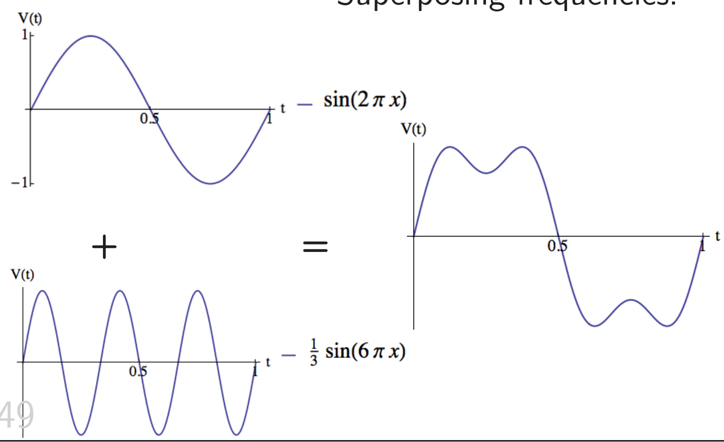
____

(36) OK, so AC vs DC?????

48

ADDITIONAL NOTES

Superposing frequencies.



49

Computer storage and communication

Computers store and transmit information in a sequence of 0s and 1s called ________________.

The physical construction of a computer is electrical, with binary digits represented by "square" electrical signals (voltage is peak or zero) or capacitors (charged or uncharged).

50

Each binary digit (0 or 1) is called a __________

A sequence of 8 binary digits is called a _____

51

The alphabet on computers

Each English character has a unique code represented by a single byte:

A	01000001
B	01000010
C	01000011
⋮	

physically represented as a sequence of charged and uncharged capacitors.

52

Do you read binary?

Probably not, but your smarter-than-you phone does:

53

ADDITIONAL NOTES

ADDITIONAL NOTES

Table 19–1 Symbols for Circuit Elements

Symbol	Device
+ -	Battery
or	Capacitor
	Resistor
–	Wire with negligible resistance
	Switch
or	Ground

1

EMF and Terminal Voltage

To get a current flowing you need a device (such as a battery) that delivers electric energy (from chemical or mechanical or light, etc.).

Such a device is called a source of ______________________________________.

The unit of $\mathcal{E}$ is volts.

2

The job of a source of $\mathcal{E}$ is to supply a fixed emf (voltage) to a circuit, or as close to it as possible.

____

The current flowing through a circuit will depend on the resistances in the circuit.

3

The rated voltage of a battery is its emf. That is the theoretical potential difference it can supply.

But when the battery is connected to a circuit, and a current starts to flow, the internal resistance of the battery causes a small voltage drop. The effective voltage of the battery is called its terminal voltage, V_{ab}, where a and b represent the two terminals of the battery.

4

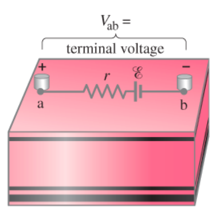


Figure 19–1

5

The next three questions refer to the circuit below:

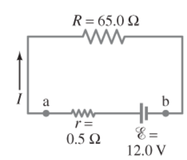


Figure 19–2

The battery has an internal resistance of 0.5Ω, as shown. The terminals of the battery are a and b.

6

ADDITIONAL NOTES

(1) What is the current in the circuit?

7

8

(2) What is the terminal voltage of the battery?

$$V_{ab} =$$

9

(3) What is the power dissipated in both resistors?

10

The internal resistance of a battery is usually small, and therefore the terminal voltage is usually very close to the emf:

$$V_{ab} \approx \mathcal{E}.$$

Unless otherwise stated, we'll assume that $V_{ab} = \mathcal{E}$ and simply call it V.

11

Resistors in Series and Parallel

An arrangement such as this is called a __________ _______________:

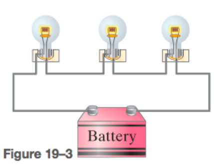


Figure 19–3

Schematically

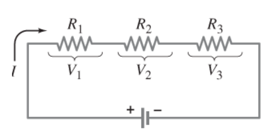


Figure 19–3

12

ADDITIONAL NOTES

Such a combination will have a total ________ ________ – the resistance that would appear to be present if all the "actual" resistors were combined:

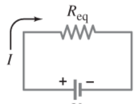


Figure 19–3

What is the equivalent resistance of resistors in series?

13

(4) Does the same current flow through each R?

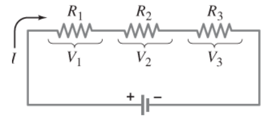


Figure 19–3

____

14

(5) Keeping in mind Ohm's Law, will the potential difference across each resistor be the same?

____

15

The total potential drop difference across all the resistors must equal the potential of the battery:

$$V = \sum V_i = \sum IR_i = I \sum R_i.$$

On the other hand, the equivalent resistance, R_{eff}, must obey

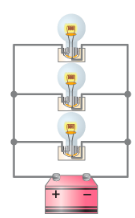
$$V = IR_{\text{eq}}.$$

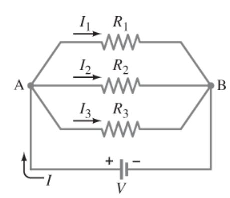
16

(6) So what's the formula for the equivalent resistance?

17

Now consider this arrangement. It's called a ______ __________:

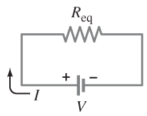




18

ADDITIONAL NOTES

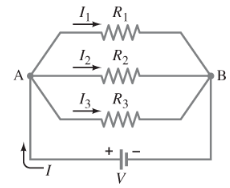
A combination such as this, too, will have a total ____________________________ – the resistance that would appear to be present if all the "actual" resistors were combined:



What's the equivalent resistance of ____________________?

19

In this case



the current splits, each part flowing through a different resistor. So

$$I = \sum I_i. \tag{1}$$

We'll also have

$$I = \frac{V}{R_{\text{eq}}} \quad \text{and} \quad I_i = \frac{V}{R_i}. \tag{2}$$

20

(7) Plug equations (2) into (1) and get a formula for R_{eq}.

21

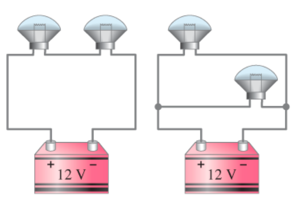
(8) What is the equivalent resistance of two $1\,\Omega$ resistors in (a) series, and (b) parallel?

(a) Series:

(b) Parallel:

22

(9) If the resistance of each lamp is R, what's the effective resistance in the two cases?



(1) Series (2) Parallel

Series:

Parallel:

23

(10) Which of the previous draws more current?

____

____

____

____

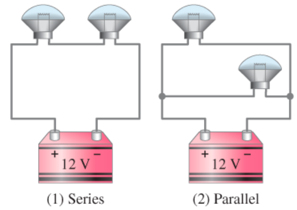
24 ____

ADDITIONAL NOTES

(11) Which uses more power?

25

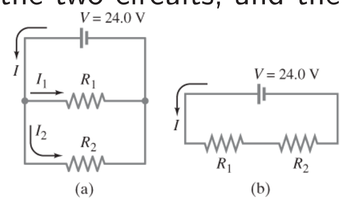
(12) Which circuit offers better safeguards against a wire being cut, or a bulb blowing?



(1) Series (2) Parallel

26

(13) If $R_1 = 2\Omega$ and $R_2 = 3\Omega$, what are the equivalent resistances of the two circuits, and the currents in all branches?



Series:

Parallel:

27

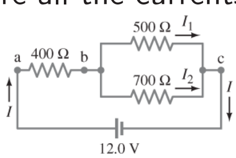
Currents

Series:

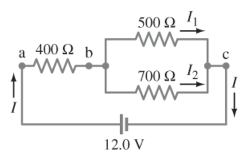
Parallel:

28

(14) What's the equivalent resistance of this circuit, and what are all the currents?



29



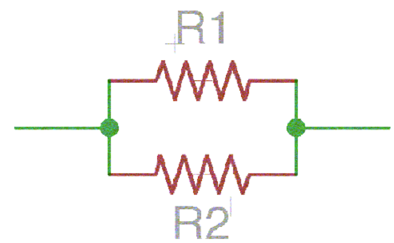
30

ADDITIONAL NOTES

$V_{ab} =$

31

Ponder this diagram:



$R_1 \neq R_2$

(15) Is the PD across R_1 the same as across R_2?

32 ________

(16) Is the current through R_1 the same as through R_2? ________________________

(17) If $R_1 > R_2$, what can you say of I_1 (current through R_1) and I_2 (current through R_2))? ____________

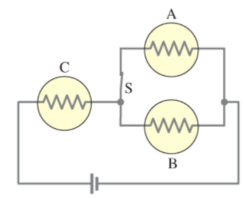
(18) Makes sense? ____________

(19) If $R_1 = R_2$, how will the current flow?

____

33

(20) Which of these bulbs will shine the brightest?



34

If the current in the circuit is I, all of it passes through bulb ________, and assuming the resistances are the same, half of it passes through

____________.

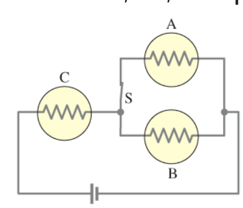
Using

____

35 ________

(21) Will C shine twice as brightly as A and B, or what? ____________

(22) What if the switch, S, is opened?



____

36 __________

ADDITIONAL NOTES

Kirchoff's Rules

The behavior of more complicated circuits can be analyzed via two rules:

K1: At any intersection, the sum of the currents entering equals the sum of the currents leaving.

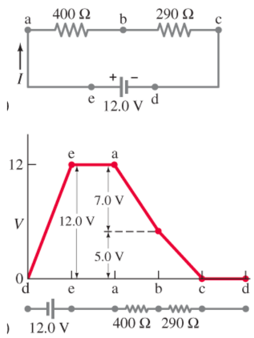
K2: Around any closed loop of a circuit, the sum of the PDs is zero.

37

(23) Rules, laws, pshaw!!!
What fundamental principles underly these?

38

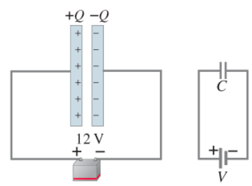
Here's how potential differences behave as you go around a circuit:



39

Capacitors in Series and Parallel

Reminder:

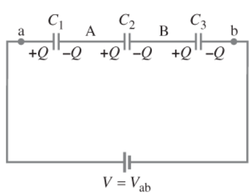


$$Q = CV$$

How does this work?

40

Series:



We know that $Q = C_i V_i$ for each capacitor. So

$$V_{ab} =$$

But we also have

$$V_{ab} =$$

41

(24) What do you get when you equate the two right-hand sides?

42

ADDITIONAL NOTES

Parallel:

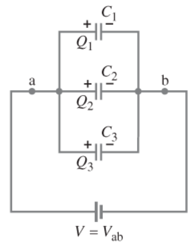


Figure 19–17

(1)

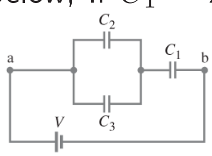
and each (2)

43

(25) Plug eqn. (2) into (1) and get C_{eq}.

44

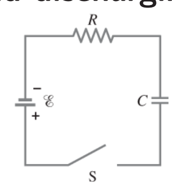
(26) What is the effective capacitance of the combination shown below, if $C_1 = 2\text{F}$, $C_2 = 3\text{F}$ and $C_3 = 5\text{F}$?



____

45

Charging and discharging capacitors



(27) What happens when you flip the switch?

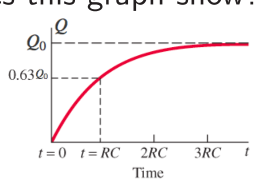
____

(28) Does it do so instantaneously? ____

(29) Does it do so linearly (constant rate)? More quickly at the start? More quickly at the end?

46

(30) What does this graph show?



____

____

47

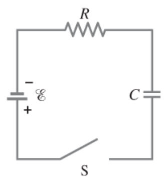
(31) Are you pleading for a formula? ________

(32) If Q swings that way, how does V_C go?

48

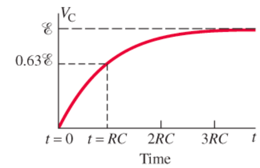
ADDITIONAL NOTES

Q_0/C is the peak voltage across the capacitor.
(33) In terms of the labeled components of the circuit below what must Q_0/C equal? __________



49

So, we have

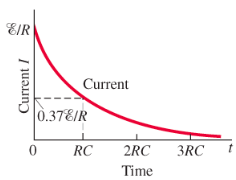


The *net* voltage in the circuit will be $\mathcal{E} - V_C$. It starts at $\mathcal{E}$ and approaches 0 as the capacitor charges.

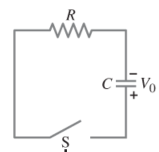
50

(34) Given a fixed resistance in the circuit, R, what will I, the current in the circuit, do?

____

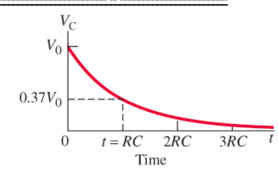


51



(35) What happens when you flip the switch?

____



52

$$V_C = V_0 e^{-t/RC} \qquad Q = Q_0 e^{-t/RC}$$

Electrical hazards

53

What's bad for you?

(36) Resistance? Current? Voltage?

____

____

____

____

____

____

54

ADDITIONAL NOTES

Harmful currents

$> 1\,$mA: Can be felt

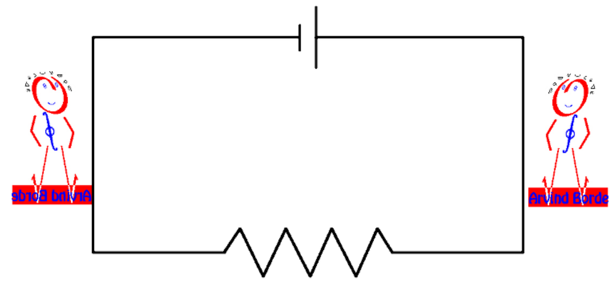
$> 10\,$mA: Muscle contractions.

$> 80\,$mA: Heart beats irregularly.

Dry skin resistance $\sim 10^4$–$10^6\,\Omega$.

Wet skin resistance $\leqslant 10^3\,\Omega$.

55



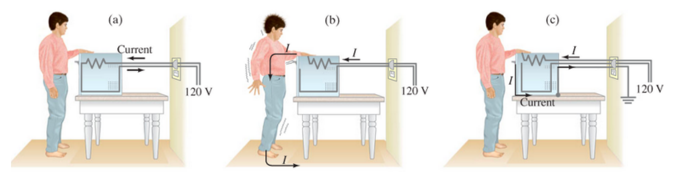
(37) Which wire should I touch, left or right?

56

A polarized plug is meant to ensure that a part of a device that you might touch accidentally is connected to the "neutral" wire, not the "hot" one.

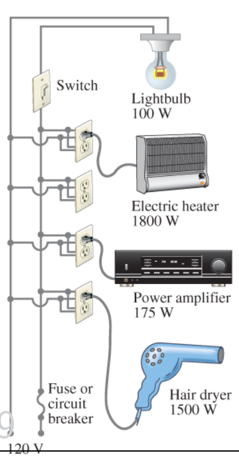
57

Grounding



The current due to faulty wiring is carried to ground on a path of lower resistance than you.

58



What a household circuit might look like.

The wattage of each device tells you how much current it draws, from $P = IV$.

For example, the hairdryer draws $I = P/V = 1500/120 = 12.5$ A.

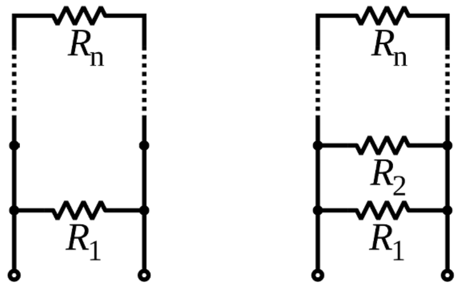
59

The total current in the circuit is the sum of the currents drawn by all the devices on the circuit.

If you connect more devices, you draw more current.

60

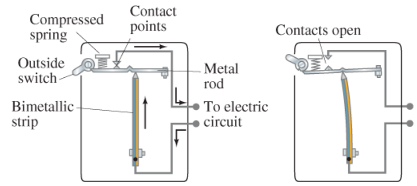
ADDITIONAL NOTES



Adding a device lowers the equivalent resistance, so draws more current.

61

If you connect too many devices, you draw too much current and cause a fire or trip a circuit breaker.



(b) Circuit breaker (closed)

(c) Circuit breaker (open)

62

ADDITIONAL NOTES

ADDITIONAL NOTES