Engineering Circuit Analysis 9th edition Hayt Solutions Manual

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1. Convert the following to engineering notation:

(a) $0.045\ \text{W} = 45\ \ 10^{-3}\ W =$ **45 mW**

(b) $2000\ \text{pJ} = 2000\ \ 10^{-12} = 2\ \ 10^{-9} J =$ **2 nJ**

(c) $0.1\ \text{ns} = 0.1\ \ 10^{-9} = 100\ \ 10^{-12} s =$ **100 ps**

(d) $39{,}212\ \text{as} = 3.9212\times10^{4}\times10^{-18} = 39.212\times10^{-15}\ \text{s} =$ **39.212 fs**

(e) **3 Ω**

(f) $18{,}000\ \text{m} = 18\ \ 10^{3} m =$ **18 km**

(g) $2{,}500{,}000{,}000{,}000\ \text{bits} = 2.5\ \ 10^{12}\ bits =$ **2.5 terabits**

(h) $\left(\frac{10^{15}\ \text{atoms}}{\text{cm}^3}\right)\left(\frac{10^{2}\ \text{cm}}{1\ \text{m}}\right)^3 =$ **10^{21} atoms/m^3** (it's unclear what a "zeta atom" is)

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2. Convert the following to engineering notation:

(a) $1230 \text{ fs} = 1.2310^{3} \quad 10^{15} = 1.23 \quad 10^{12} \; s =$ 1.23 ps

(b) $0.0001 \text{ decimeter} = 1 \quad 10^{4} \quad 10^{1} = 10 \quad 10^{6} \; m =$ 10 µm

(c) $1400 \text{ mK} = 1.4 \quad 10^{3} \quad 10^{3} =$ $1.4 \; K$

(d) $32 \text{ nm} = 32 \quad 10^{9} m =$ 32 nm

(e) $13{,}560 \text{ kHz} = 1.356 \quad 10^{4} \quad 10^{3} = 13.56 \quad 10^{6} \; Hz =$ 13.56 MHz

(f) $2021 \text{ micromoles} = 2.021 \quad 10^{3} \quad 10^{6} = 2.021 \quad 10^{3} \; moles =$ 2.021 millimoles

(g) $13 \text{ deciliters} = 13 \quad 10^{1} =$ $1.3 \; liters$

(h) 1 hectometer = $100 \; meters$

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3. Express the following in engineering units:

(a) 1212 mV = 1.121 V

(b) 10^{11} pA = $10^{11} \times 10^{-12}$ = 100 mA

(c) 1000 yoctoseconds = $1 \quad 10^{3} \quad 10^{24} = 1 \quad 10^{21}$ *seconds* = 1 zs

(d) 33.9997 zeptoseconds

(e) 13,100 attoseconds $= 1.31 \times 10^{-15}$ s = 1.31 fs

(f) 10^{-14} zettasecond = $10^{-14} \times 10^{21} = 10^{7} = 10 \times 10^{6}$ s = 10 Ms

(g) 10^{-5} second $= 10 \quad 10^{6}$ *seconds* = 10 μs

(h) 10^{-9} Gs = $10^{9} \quad 10^{9}$ = 1 *second*

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4. Expand the following distances in simple meters:

(a) 1 Zm $= 1 \quad 10^{21} \; m$
(b) 1 Em $= 1 \quad 10^{18} \; m$
(c) 1 Pm $= 1 \quad 10^{15} \; m$
(d) 1 Tm $= 1 \quad 10^{12} \; m$
(e) 1 Gm $= 1 \quad 10^{9} \; m$
(f) 1 Mm $= 1 \quad 10^{6} \; m$

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5. Convert the following to SI units, taking care to employ proper engineering notation:

(a) $212°F = (212-32)\frac{5}{9} + 273.15 = \boxed{373.15\ \text{K}}$

(b) $0°F = (0-32)\frac{5}{9} + 273.15 = \boxed{255.37\ \text{K}}$

(c) $\boxed{0\ \text{K}}$

(d) $200\ \text{hp} = 200\frac{745.7\ W}{1\ hp} = 1.4914 \quad 10^5\ W = 149.14 \quad 10^3\ W = \boxed{149.14\ \text{kW}}$

(e) $1\ \text{yard} = 0.9144\ m = \boxed{914.4\ mm}$

(f) $1\ \text{mile} = 1\frac{1760\ yards}{1\ mile}\frac{0.9144\ m}{1\ yard} = 1{,}609.3\ m = \boxed{1.6093\ km}$

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6. Convert the following to SI units, taking care to employ proper engineering notation:

(a) 373.15 K

(b) 273.15 K (already in SI)

(c) 4.2 K

(d) $150\text{ hp} = 150\dfrac{745.7\ W}{1\ hp} = 1.11855\quad 10^5\ W = 111.855\quad 10^3\ W\ = 111.855\text{ kW}$

(e) $500\text{ Btu} = 500\dfrac{1055\ J}{1\ Btu} = 5.275\quad 10^5\ J = 527.5\quad 10^3\ J = 527.5\ kJ$

(f) $100\text{ J/s} = 100\ W$

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7. It takes you approximately 2 hours to finish your homework on thermodynamics. Since it feels like it took forever, how many galactic years does this correspond to? (1 galactic year = 250 million years)

$$2\ hours\ \frac{1\ day}{24\ hours}\ \frac{1\ year}{365\ days}\ \frac{galactic\ years}{250\ \ 10^{6}\ years} = \boxed{913.24\ \ 10^{-15}\ galactic\ years}$$

(or, 913.24 femto-galactic-years!)

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8. A certain krypton fluoride laser generates 15 ns long pulses, each of which contains 550 mJ of energy.

(a) Calculate the power using the pulse energy over the 15 ns duration.

$$p = \frac{w}{t} = \frac{550\ mJ}{15\ ns} = \frac{550\quad 10^{-3}\ J}{15\quad 10^{-9}\ s} = 3.6667\quad 10^{7}\ W = \boxed{36.667\ MW}$$

(b) If up to 100 pulses can be generated per second, calculate the maximum average power output of the laser. In this case, look at the total energy of 100 pulses over the one second duration.

$$p = \frac{w}{t} = \frac{100\ pulses\ \ 550\ mJ}{1\ s} = \boxed{55\ W}$$

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9. Your recommended daily food intake is 2,500 food calories (kcal). If all of this energy is efficiently processed, what would your average power output be?

$$2500 \quad 10^3 \ cal \quad \frac{4.187 \ J}{cal} = 10.4675 \quad 10^6 \ J$$

$$p = \frac{w}{t} = \frac{10.4675 \quad 10^6 \ J}{(24 \ h/day)(60 \ min/h)(60 \ s/min)} = \boxed{121.15 \ W}$$

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10. An electric vehicle is driven by a single motor rated at 40 hp. If the motor is run continuously for 3 h at maximum output, calculate the electrical energy consumed. Express your answer in SI units using engineering notation.

$$w = pt = \left(40\ hp \frac{745.7\ W}{1\ hp}\right)\left(3\ h \frac{3600\ s}{1\ h}\right) = 3.2214 \times 10^8\ J = 322.14 \times 10^6\ J$$

$$= \boxed{322.14\ \text{MJ}}$$

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11. Under insolation conditions of 500 W/m^2 (direct sunlight), and 10% solar cell efficiency (defined as the ratio of electrical output power to incident solar power), calculate the area required for a photovoltaic (solar cell) array capable of running the vehicle in Exercise 10 at half power.

$$p = 20\ hp = 20\ hp\ \ \frac{745.7\ W}{1\ hp} = 14.914\ \ \ 10^3\ W$$

$$p = 14.914 \times 10^3\ W = \left(500 \frac{W}{m^2}\right)(area)(10\%\ efficiency)$$

$$area = \frac{14.914\ \ \ 10^3\ W}{(500)(0.1)} = \boxed{298.28\ m^2}$$

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12. A certain metal oxide nanowire piezoelectricity generator is capable of producing 100 pW of usable electricity from the type of motion obtained from a person jogging at a moderate pace.

(a) $$\frac{1\ W}{100\quad 10^{-12}\ W/nanowire} = \boxed{10^{10}\ nanowires}$$

(b) $$\frac{10^{10}\ nanowires}{5\ nanowires/\quad m^2} = 2\quad 10^{9}\quad m^2 \frac{1\ m^2}{\left(10^{6}\right)^2\quad m^2} = \boxed{2\quad 10^{-3} m^2}$$

This area would fit in a square that is approximately 4.5 cm x 4.5 cm, so very reasonable!

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13. Assuming a global population of 9 billion people, each using approximately 100 W of power continuously throughout the day, calculate the total land area that would have to be set aside for photovoltaic power generation, assuming 800 W/m^2 of incident solar power and a conversion efficiency (sunlight to electricity) of 10%.

$$Power\ \ needed = \left(Power\ \ density\ \ from\ Sun\right)\left(Area\right)\left(Conversion\ \ Efficiency\right)$$

$$Area = \frac{\left(100\ W\right)\left(910^9\ \ people\right)}{\left(800\ W/m^2\right)\left(0.10\right)} = \boxed{1.12510^{10}\ \ m^2 = 11{,}250\ \ km^2}$$

About the size of the state of Connecticut.

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14. The total charge flowing out of one end of a small copper wire and into an unknown device is determined to follow the relationship $q(t) = 5e^{-t/2}$ C, where t is expressed in seconds. Calculate the current flowing into the device, taking note of the sign.

$$i = \frac{dq}{dt} = \frac{d}{dt}\left(5e^{\frac{t}{2}}\right) = \boxed{2.5e^{\frac{t}{2}}\ A}$$

Note that the charge on the device starts positive, and then decreases. This means that current is flowing out of the device. The current flowing into the devices is therefore negative.

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15. The current flowing into the collector lead of a certain bipolar junction transistor (BJT) is measured to be 1 nA. If no charge was transferred in or out of the collector lead prior to t = 0, and the current flows for 1 min, calculate the total charge which crosses into the collector.

$$q = \int idt = \left(10^{-9}\ A\right)\left(60\ s\right) = 60 \times 10^{-9}\ C = \boxed{60\ nC}$$

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16. The total charge stored on a 1 cm diameter insulating plate is -10^{13} C.

(a) $$\frac{10^{13} C}{1.602 \quad 10^{-19} \ C / electron} = \boxed{6.242 \quad 10^{31} \ electrons}$$

(b) $$\frac{6.242 \quad 10^{31} \ electrons}{(3.1416)(0.005 \ m)^2} = \boxed{7.9475 \quad 10^{35} \ electrons / m^2}$$

(c) $$i = \frac{dq}{dt} = \frac{10^6 \ electrons}{s}\left(\quad 1.602 \quad 10^{-19} \ C\right) = \quad 1.602 \quad 10^{-13} \ A = \boxed{160.2 \ fA}$$

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17. A mysterious device found in a forgotten laboratory accumulates charge at a rate specified by the expression q(t)=9−10t C from the moment it is switched on.

(a) 9 C

(b) −1 C

(c) $i = \frac{dq}{dt} = 10\frac{C}{s} = 10\ A$, The current is constant (time independent)

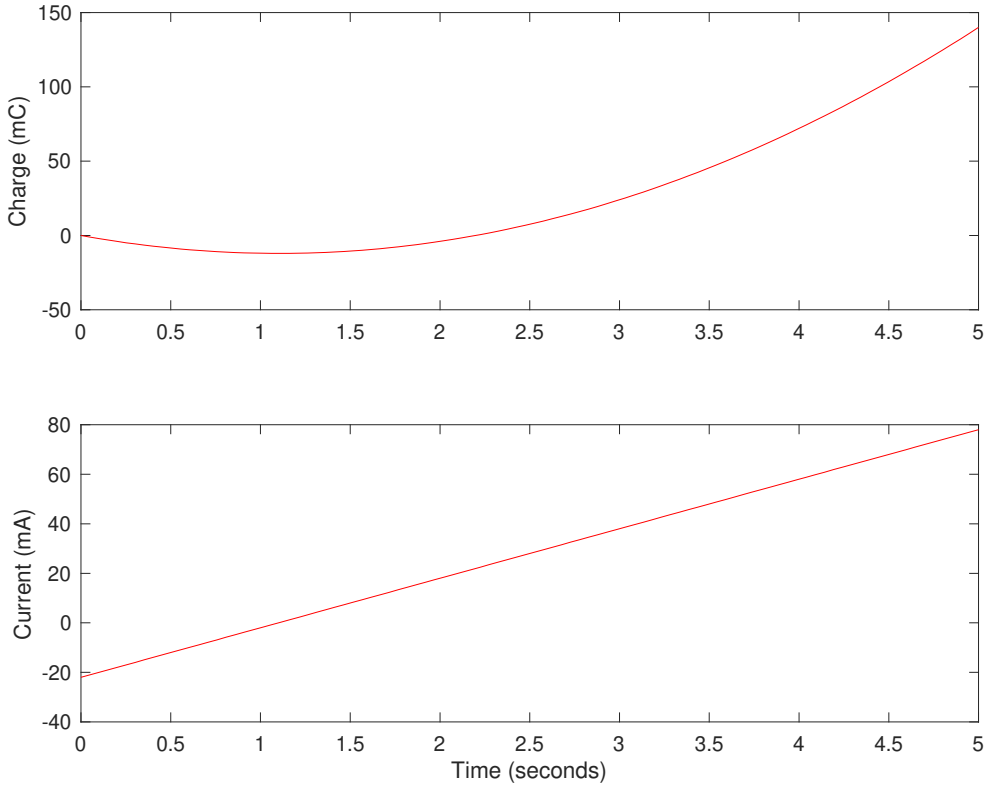
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18. A new type of device appears to accumulate charge according to the expression $q(t)=10t^2 - 22t$ mC (t in s).

(a) $$i = \frac{dq}{dt} = 20t \quad 22\frac{mC}{s} = 20t \quad 22\ mA$$

$$i = 0\ at\ t = \frac{22}{20}s = \boxed{1.1\ s}$$

(b) Sketch q(t) and i (t) over the interval $0 \le t < 5$ s.




```
t_end = 5;    % End time in seconds
t_pts = 100; % Number of points for time vector
t=linspace(0,t_end,t_pts);  % Define time vector

for i=1:t_pts; % Iterate for each point in time
    charge(i)=10*t(i)^2-22*t(i);
    current(i)=20*t(i)-22;
end

figure(1)
subplot(2,1,1); plot(t,charge,'r'); % Plot charge
ylabel('Charge (mC)');

subplot(2,1,2); plot(t,current,'r') % Plot current
ylabel('Current (mA)')
```

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```
xlabel('Time (seconds)')
```

19. The current flowing through a tungsten-filament light bulb is determined to follow i (t) = 114 sin(100πt) A.

(a) The interval corresponds to 100 periods. The current crosses zero at every half period and full period, as well as at time t=0. The current equals zero 201 times in the interval from t=0 to t=2s.

(b) How much charge is transported through the light bulb in the first second?

$$q = \int_0^{1\,s} 114\sin\left(100\ \ t\right)dt = \ \ 114\left(100\ \ \right)\left[\cos\left(100\ \ \right)\ \ \cos\left(0\right)\right] = 0$$

Current flows in and out of the light bulb each period. Since the time period is over an integer number of periods, the total charge is zero.

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20. The current waveform depicted in Fig. 2.28 is characterized by a period of 8 s.

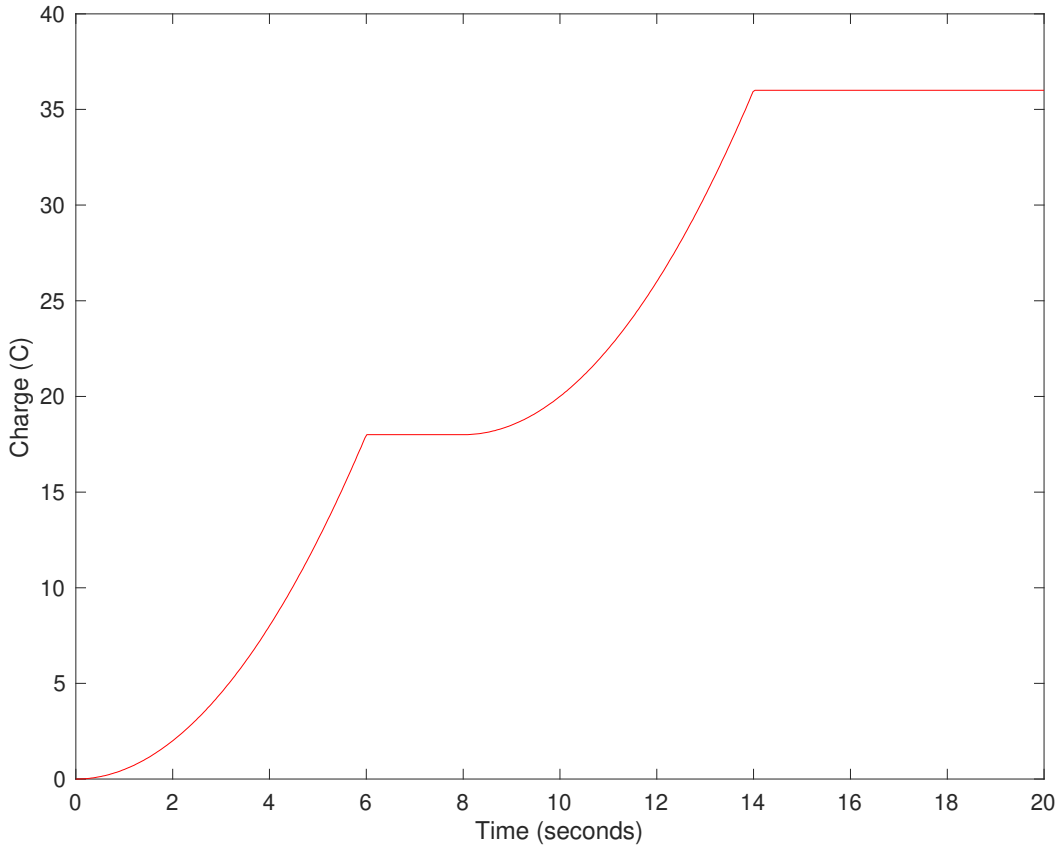
(a) The average value is the integral of the function divided by the time period.

$$\frac{\int_0^{6\ s} t\ dt + 0}{8\ s} = \frac{18}{8} = \boxed{2.25\ A}$$

(b) $q = \int i\ dt$

$$i(t) = \begin{cases} t & 0 < t < 6 \\ 0 & 6 < t < 8 \\ (t - 8) & 8 < t < 14 \\ 0 & 14 < t < 20 \end{cases}$$

$$q(t) = \begin{cases} t^2/2 & 0 < t < 6 \\ 18 & 6 < t < 8 \\ 18 + (t - 8)^2/2 & 8 < t < 14 \\ 36 & 14 < t < 20 \end{cases}$$



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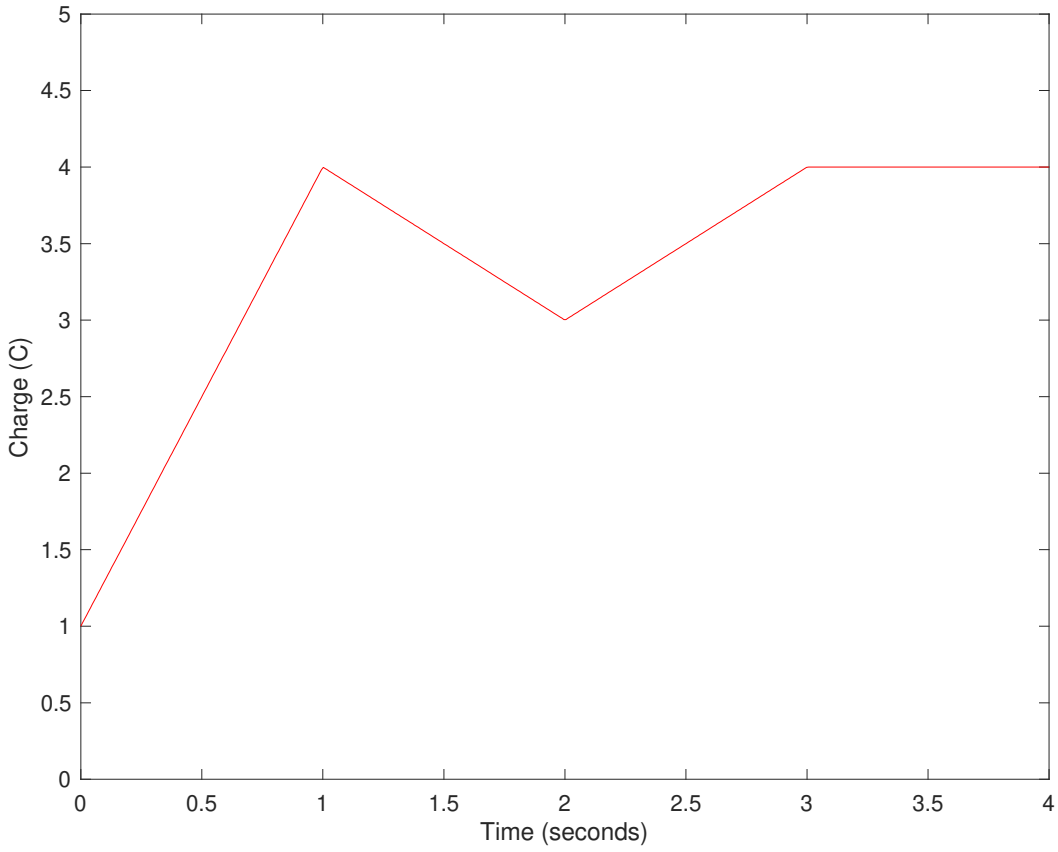
21. The current waveform depicted in Fig. 2.29 is characterized by a period of 4 s.

(a) $$i_{avg} = \frac{3 \quad 1+1+0}{4} = \boxed{0.75\ A}$$

(b) $$i_{avg} = \frac{1+1}{2} = \boxed{0\ A}$$

(c) $$i(t) = \begin{cases} 3A & 0 < t < 1 \\ 1A & 1 < t < 2 \\ 1A & 2 < t < 3 \\ 0 & 3 < t < 4 \end{cases}$$

$$q(t) = \int i(t)dt = \begin{cases} 3t + q(0) = 3t + 1\ \text{C}, & 0 \le t \le 1\ \text{s} \\ -t + 1 + q(1) = -t + 5\ \text{C}, & 1 \le t \le 2\ \text{s} \\ t - 2 + q(2) = t + 1\ \text{C}, & 2 \le t \le 3\ \text{s} \\ q(3) = 4\ \text{C}, & 3 \le t \le 4\ \text{s} \end{cases}$$

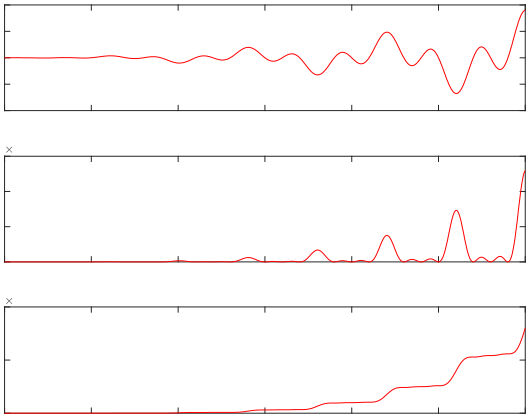


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22 A wind power system with increasing windspeed has the current waveform described by the equation below, delivered to an 80 Ω resistor. Plot the current, power, and energy waveform over a period of 60 seconds, and calculate the total energy collected over the 60 second time period.

$$i(t) = \frac{1}{2}t^2 \sin\left(\frac{1}{8}t\right)\cos\left(\frac{1}{4}t\right) A$$

From calculations, $w(t{=}60\text{ s}) = 801.87{\times}10^6$ J



```
% Matlab code for plotting wind power waveform

t_end = 60;    % End time in seconds
t_pts = 600; % Number of points for time vector
t=linspace(0,t_end,t_pts);  % Define time vector
dt=t_end/t_pts; % Separation between time points

R=80; % Resistance in ohms

for i=1:t_pts; % Iterate for each point in time
    current(i)=0.5*t(i)^2*sin(pi/8*t(i))*cos(pi/4*t(i));
    p(i)=current(i)^2*R;
end

w=cumsum(p)*dt; % Energy from cumulative sum times time separation

figure(1)
subplot(3,1,1); plot(t,current,'r'); % Plot voltage
ylabel('Current (A)');

subplot(3,1,2); plot(t,p,'r') % Plot power
ylabel('Power (W)')

subplot(3,1,3); plot(t,w,'r') % Plot energy
xlabel('Time (seconds)')
ylabel('Energy (J)')
```

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23. Two metallic terminals protrude from a device. The terminal on the left is the positive reference for a voltage called v_x (the other terminal is the negative reference). The terminal on the right is the positive reference for a voltage called v_y (the other terminal being the negative reference). If it takes 1 mJ of energy to push a single electron into the left terminal, determine the voltages v_x and v_y .

$$v_x = \frac{10^{-3} J}{1.602 \quad 10^{-19} C} = \boxed{6.2422 \quad 10^{15} V} \text{ !}$$

$$v_y = \quad v_x = \boxed{6.2422 \quad 10^{15} V}$$

Note that this value is very large, since a potential of 1 V only requires 1.602×10^{-19} J to push one electron across the terminals.

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24. The convention for voltmeters is to use a black wire for the negative reference terminal and a red wire for the positive reference terminal.

(a) Voltage looks at the electric potential difference between two terminals. Potential difference relates two different points/terminals.

(b) The sign of the voltage will change (positive to negative, or negative to positive)

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25. Determine the power absorbed by each of the elements in Fig. 2.30.

(a)

$$p = vi = (6\ V)(1\ pA) = \boxed{6\ pW}$$

(b)

$$p = vi = (1\ V)(10\ mA) = \boxed{10\ mW}$$

(c)

$$p = vi = (10\ V)(\ 2\ A) = \boxed{20\ W}$$

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26. Determine the power absorbed by each of the elements in Fig. 2.31.

(a)

$$p = vi = (2\ V)(\ 1\ A) = \boxed{2\ W}$$

(b)

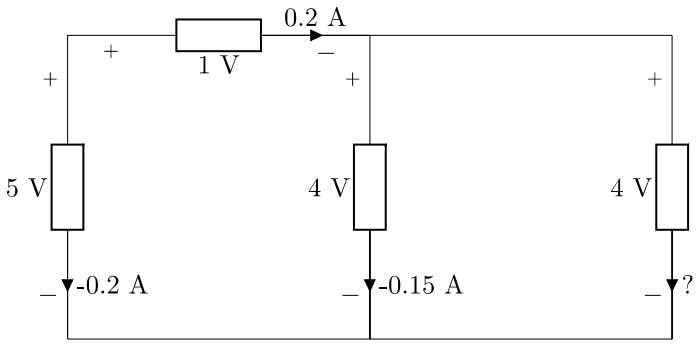
$$p = vi = (\ 16e^{0.5}\ V)(8e^{0.5}\ mA) = \boxed{47.0886\ mW}$$

(c)

$$p = vi = (2\ V)(\ 10010^{3}\ mA) = \boxed{0.2\ mW}$$

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27. Determine the unknown current for the circuit in Figure 2.32, and find the power that is supplied or absorbed by each element. Confirm that the total power is zero.



5 V element: $p = vi = (5\ V)(\ 0.2\ A) =$ $1\ W\ (supplies\ 1\ W)$

1 V element: $p = vi = (1\ V)(0.2\ A) =$ $0.2\ W\ (absorbs\ 0.2\ W)$

4 V element on left: $p = vi = (4\ V)(\ 0.15\ A) =$ $0.6\ W\ (supplies\ 0.6\ W)$

4 V element on right: since total power must sum to zero, must be absorbing 1.4 W

$I = 0.35$ A

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28. A constant current of 1 ampere is measured flowing into the positive reference terminal of a pair of leads whose voltage we'll call v_p. Calculate the absorbed power at t = 1 s if $v_p(t)$ equals

(a) $p = (1\ V)(1\ A) = \boxed{1\ W}$

(b) $p = (\ 1\ V)(1\ A) = \boxed{\ 1\ W}$

(c) $p = (2+5\cos(5)\ V)(1\ A) = \boxed{3.4183\ W}$

(d) $p = (4e^{\ 2}\ V)(1\ A) = \boxed{0.5413\ W}$

(e) A negative value for absorbed power implies that the circuit element is supplying power.

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29. Determine the power supplied by the leftmost element in the circuit of Fig. 2.33.

$$p = (2\ V)(2\ A) = \boxed{4\ W}$$

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30. The current-voltage characteristic of a silicon solar cell exposed to direct sunlight at noon in Florida during midsummer is given in Fig. 2.34. It is obtained by placing different sized resistors across the two terminals of the device and measuring the resulting currents and voltages.

(a) 3 A (where voltage is zero)

(b) 0.5 V (where current is zero)

(c) Maximum power is where the product of current and voltage is maximum. This is approximately where the "knee" in the current vs voltage curve is.

$p \quad (0.375\ V)(2.5\ A) \quad 0.94\ W$

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31. A particular electric utility charges customers different rates depending on their daily rate of energy consumption: \$0.05/kWh up to 20 kWh, and \$0.10/kWh for all energy usage above 20 kWh in any 24 hour period.

(a) $$\frac{\$10}{week}\frac{1\ week}{7\ days} = \$1.4286 / day$$

First 20 kWh = \$1/day
Leaving \$0.4286/day @ \$0.10/kWh, or 4.286 kWh
Can use a total of 24.286 kWh/day

$$p = \frac{w}{t} = \frac{24.286\ kWh}{24\ h} = 1.0119\ kW = 1{,}011.9\ W$$

Total of 10 light bulbs can be run continuously to stay below \$10/week.

(b) $$w = pt = (2000kW)(24h) = 48{,}000\ kWh$$

20 kWh = \$1/day
Remaining 47,980 kWh costs \$4,798

Total cost is \$4,799 each day

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32. The Tilting Windmill Electrical Cooperative LLC Inc. has instituted a differential pricing scheme aimed at encouraging customers to conserve electricity use during daylight hours, when local business demand is at its highest. If the price per kilowatthour is \$0.033 between the hours of 9 p.m. and 6 a.m., and \$0.057 for all other times, how much does it cost to run a 2.5 kW portable heater continuously for 30 days?

For each day, the heater is run at the \$0.033/kWh rate for 9 hours and \$0.057/kWh rate for 15 hours.

Cost each day is (2.5kW)(9h)(\$0.033/kWh) + (2.5kW)(15h)(\$0.057/kWh) = \$2.88

For 30 days, cost is \$86.40

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33. A laptop computer consumes an average power of 20 W. The rechargeable battery has a voltage of 12 V and capacity of 5800 mAh. How long can the laptop run on a single battery charge?

$$w = pt$$

$$t = \frac{w}{p} = \frac{(12\ V)(5.8\ Ah)}{20\ W} = \boxed{3.48\ hours}$$

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34. You have just installed a rooftop solar photovoltaic system that consists of 40 solar modules that each provide 180 W of power under peak sunlight conditions. Your location gets an average of 5 hours of peak sunlight per day. If electricity in your area is valued at 15¢/kWh, what is the annual value of the electricity generated by your installation?

$$(40\ panels)(180\ W)(5\ h) = 36{,}000\ \frac{Wh}{day} = 36\ \frac{kWh}{day}$$

$$36\ \frac{kWh}{day}\quad \frac{365\ days}{year}\quad \frac{\$0.15}{kWh} = \boxed{\$1{,}971/\ year}$$

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35. A portable music player requiring 5 W is powered by a 3.7 V Li-ion battery with capacity of 4000 mAh. The battery can be charged by a charger providing a current of 2 A with an efficiency of 80%.

(a) $$t = \frac{w}{p} = \frac{(3.7\ V)(4\ Ah)}{5\ W} = \boxed{2.96\ hours}$$

(b) $$t = \frac{q}{i0.8} = \frac{4\ Ah}{(2\ A)(0.8)} = \boxed{2.5\ hours}$$

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36. Some of the ideal sources in the circuit of Fig. 2.31 are supplying positive power, and others are absorbing positive power. Determine which are which, and show that the algebraic sum of the power absorbed by each element (taking care to preserve signs) is equal to zero.

Supplying power: 2 A current source, 8 V voltage source, 10 V voltage source
Absorbing power: -4A current source, -3A current source

Power absorbed by each element:

2 A current source:	- 4 W
8 V voltage source:	-16 W
10 V voltage source:	-50 W
-4A current source:	40 W
-3A current source:	30 W

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37. You are comparing an old incandescent light bulb with a newer high efficiency LED light bulb. You find that they both have the same output of 800 lumens, which corresponds to approximately 5 W of optical power. However, you find that the incandescent bulb is consuming 60 W of electrical power, and the LED bulb is consuming 12 W of electrical power. Why do the optical and electrical powers not agree? Doesn't conservation of energy require the two quantities to be equal?

The electrical power is conserved in the circuit, but not all of the power is converted to light. The incandescent bulb consumes 60 W, but only 5 W is converted to light, the rest is wasted as heat or otherwise. The LED bulb consumes 12 W of electrical power, where 5 W is converted to light, and 7 W is wasted as heat or otherwise.

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38. Refer to the circuit represented in Fig. 2.35, while noting that the same current flows through each element. The voltage-controlled dependent source provides a current which is 5 times as large as the voltage V_x .

(a) Current is determined by the dependent source: i=(5)(2)=10 A

Power absorbed for V_X voltage source: $p = (2\ V)(\ 10\ A) = 20\ W$

Power absorbed for element A: $p = (10\ V)(10\ A) = 100\ W$

Power absorbed for 5 V_X dependent current source: $p = (8\ V)(\ 10\ A) = 80\ W$

(b) Element A is absorbing power, passive.

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39. Refer to the circuit represented in Fig. 2.35, while noting that the same current flows through each element. The voltage-controlled dependent source provides a current which is 5 times as large as the voltage Vx .

(a) For V_R = 100 V and V_X = 92 V, determine the power supplied by each element.

Current through dependent source is I = (5)(92) = 460 A

Power supplied for Vx source: $p = (92\ V)(460\ A) = 42.32\ \ 10^3\ W$

Power supplied for element A: $p = (100\ V)(\ \ 460\ A) = \ \ 46\ \ \ 10^3\ W$

Power supplied for 5Vx dependent source: $p = (8\ V)(460\ A) = 3.68\ \ \ 10^3\ W$

(b) 42.32 kW + 3.68 kW – 46 kW = 0

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40. The circuit depicted in Fig. 2.36 contains a dependent current source; the magnitude and direction of the current it supplies are directly determined by the voltage labeled v_1. Note that therefore $i_2 = -3v_1$. Determine the voltage v_1 if $v_2 = 33i_2$ and $i_2 = 100$ mA.

$$i_2 = \quad 3v_1 = 100mA$$

$$v_1 = \frac{i_2}{3} = \frac{100\ mA}{3} = \boxed{33.333\ mV}$$

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41. The dependent source in the circuit of Fig. 2.37 provides a voltage whose value depends on the current i_x . What value of ix is required for the dependent source to be supplying 1 W?

$$p = vi = \left(2i_x \right)\left(i_x \right) = 1\ W$$

$$i_x = \frac{1}{\sqrt{2}} = 0.7071\ A$$

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42. Determine the magnitude of the current flowing through a 4.7 kΩ resistor if the voltage across it is

(a) $i = \frac{v}{R} = \frac{0.001\ V}{4{,}700\ \Omega} = \boxed{212.77 \quad 10^{-9}\ A}$

(b) $i = \frac{v}{R} = \frac{10\ V}{4{,}700\ \Omega} = \boxed{2.1277 \quad 10^{-3}\ A}$

(c) $i = \frac{v}{R} = \frac{4e^{-t}\ V}{4{,}700\ \Omega} = \boxed{851.064 \quad 10^{-6} e^{-t}\ A}$

(d) $i = \frac{v}{R} = \frac{100\cos(5t)\ V}{4{,}700\ \Omega} = \boxed{21.277 \quad 10^{-3}\cos(5t)\ A}$

(e) $i = \frac{v}{R} = \frac{7\ V}{4{,}700\ \Omega} = \quad 1.4894 \quad 10^{-3}\ A$

Or since the problem statement asks for magnitude, $i = \boxed{1.4894 \times 10^{-3}\ \text{A}}$

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43. Real resistors can only be manufactured to a specific tolerance, so that in effect the value of the resistance is uncertain. For example, a 1 _ resistor specified as 5% tolerance could in practice be found to have a value anywhere in the range of 0.95 to 1.05 _. Calculate the voltage across a 2.2 k_ 10% tolerance resistor if the current flowing through the element is

(a) $v_{min} = iR_{min} = (0.001\ A)(0.9 \quad 2{,}200\ \Omega) = \boxed{1.9800\ V}$

$v_{max} = iR_{max} = (0.001\ A)(1.1 \quad 2{,}200\ \Omega) = \boxed{2.4200\ V}$

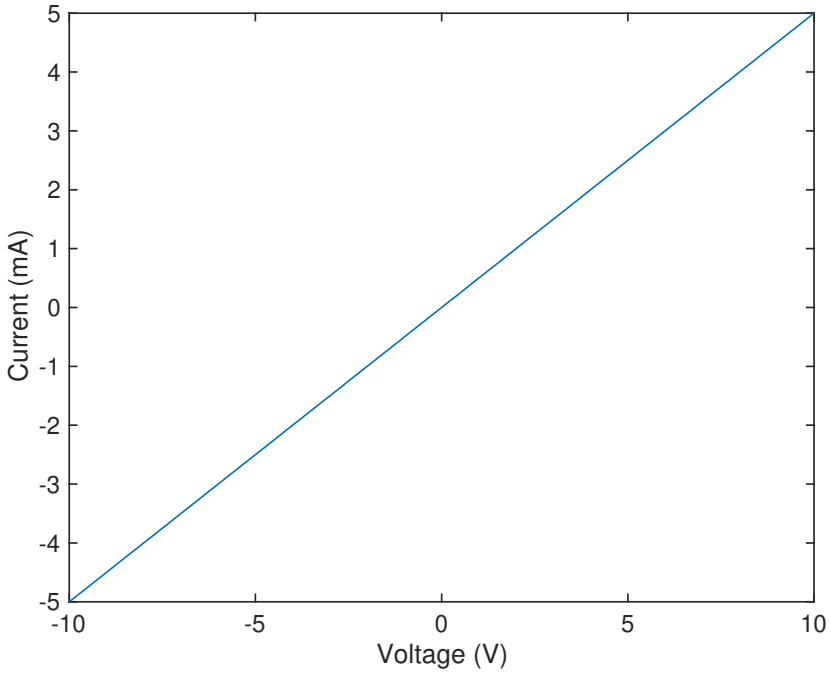
(b) $v_{min} = iR_{min} = (0.004\sin(44t)\ A)(0.9 \quad 2{,}200\ \Omega) = \boxed{7.9200\ \sin(44t)V}$

$v_{max} = iR_{max} = (0.004\sin(44t)\ A)(1.1 \quad 2{,}200\ \Omega) = \boxed{9.6800\ \sin(44t)V}$

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44.

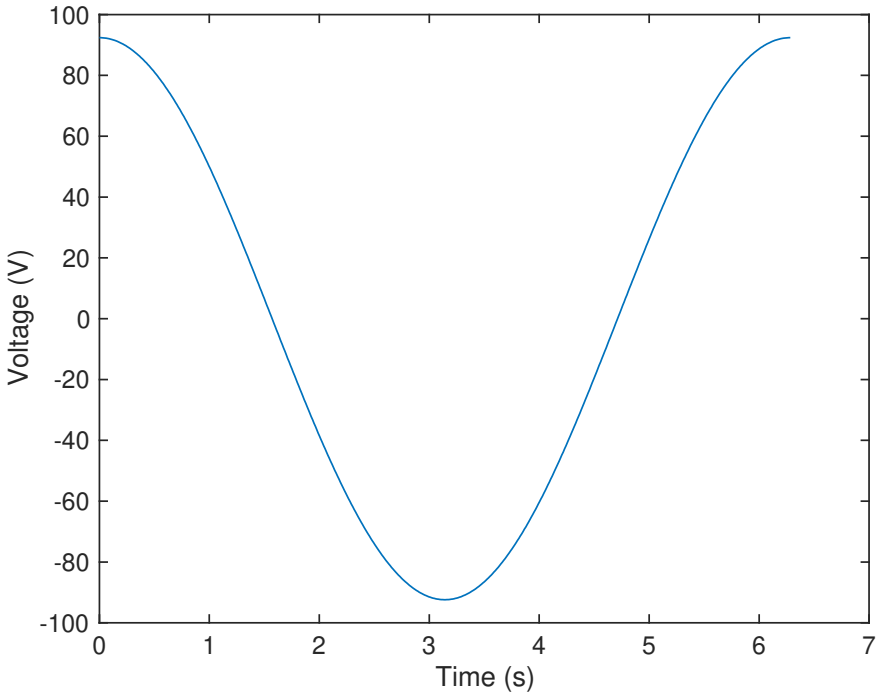
(a)



(b) $G = \frac{i}{v} = \frac{1}{R} = \boxed{500 \quad 10^{6} \; S}$

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45. Sketch the voltage across a 33 Ω resistor over the range $0 < t < 2\pi$ s, if the current is given by 2.8 cos(t) A. Assume both the current and voltage are defined according to the passive sign convention.



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46. Figure 2.38 depicts the current-voltage characteristic of three different resistive elements. Determine the resistance of each, assuming the voltage and current are defined in accordance with the passive sign convention.

$$R = \frac{v}{i}$$

(a) $R = \frac{v}{i} = \frac{5V}{0.05 \times 10^{-3}} = 100 \times 10^{3} = 100\ k\Omega$

(b) $R = \frac{v}{i} = \frac{5\ V}{0\ A} =$

(c) $R = \frac{v}{i} = \frac{0\ V}{\quad} = 0$

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47. Examine the I-V characteristics in Figure 2.38. Which would be the most desirable for a fuse? Explain.

The fuse should have low resistance, or pass current without a voltage drop. The most desirable would be (c), with a pre-defined current where the fuse would blow.

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48. Determine the conductance (in siemens) of the following:

(a) $G = \frac{1}{R} = \frac{1}{0} =$

(b) $G = \frac{1}{100 \quad 10^6} = 10 \quad 10^{9} \; S$

(c) $G = \frac{1}{200 \quad 10^{3}} = 5 \; S$

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49. Determine the magnitude of the current flowing through a 10 mS conductance if the voltage across it is

(a) $i = Gv = (0.01)(0.002) = 20 \quad 10^{6} \; A = \boxed{20 \quad A}$

(b) $i = Gv = (0.01)(\quad 1) = \quad 10 \quad 10^{3} \; A = \quad 10 \; mA$

(or since it asks for magnitude, $i = \boxed{10 \; mA}$)

(c) $i = Gv = (0.01)(100e^{2t}) = \boxed{1e^{2t} \; A}$

(d) $i = Gv = (0.01)(5\sin 5t) = 0.05\sin 5t \; A = \boxed{50\sin 5t \; mA}$

(e) $i = Gv = (0.01)(0) = \boxed{0}$

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50. A 1% tolerance 1 kΩ resistor may in reality have a value anywhere in the range of 990 to 1010 Ω. Assuming a voltage of 9 V is applied across it, determine

(a) The corresponding range of current is

$$i_{min} = \frac{v}{R_{max}} = \frac{9}{1010} = 8.9109 \quad 10^{-3} \; A = \boxed{8.9109 \; mA}$$

$$i_{max} = \frac{v}{R_{min}} = \frac{9}{990} = 9.0909 \quad 10^{-3} \; A = \boxed{9.0909 \; mA}$$

(b) The corresponding range of absorbed power is

$$p_{min} = vi_{min} = (9 \; V)(8.9109 \; mA) = \boxed{80.1981 \; mW}$$

$$p_{max} = vi_{max} = (9 \; V)(9.0909 \; mA) = \boxed{81.8181 \; mW}$$

(c) Repeating for 10% tolerance

$$i_{min} = \frac{v}{R_{max}} = \frac{9}{1100} = 8.1818 \quad 10^{-3} \; A = \boxed{8.1818 \; mA}$$

$$i_{max} = \frac{v}{R_{min}} = \frac{9}{900} = 10 \quad 10^{-3} \; A = \boxed{10 \; mA}$$

$$p_{min} = vi_{min} = (9 \; V)(8.1818 \; mA) = \boxed{73.6362 \; mW}$$

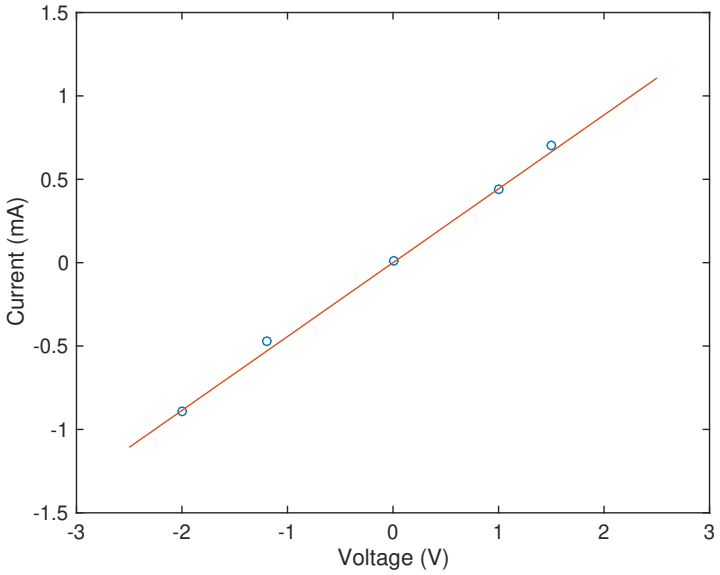
$$p_{max} = vi_{max} = (9 \; V)(10 \; mA) = \boxed{90 \; mW}$$

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51. The following experimental data is acquired for an unmarked resistor, using a variable-voltage power supply and a current meter. The current meter readout is somewhat unstable, unfortunately, which introduces error into the measurement.

(a)



(b) R=2.2583 kΩ

```
% Matlab code
% Measured points
vm=[-2 -1.2 0 1 1.5];
im=[-0.89 -0.47 0.01 0.44 0.7];

% Get linear fit
% Note that this is not perfect, since the fit does not go through the
% origin. For a perfect fit, will need to use a more involved fit such as
% lsqlin with the Matlab optimization toolbox
% The first order poly fit will return the slope and intercept of the best
% line fit
[P]=polyfit(vm,im,1);

% Construct curve for linear fit to plot
v = linspace(-2.5,2.5,100);

for i = 1:100
    I(i) = v(i)*P(1);
end

R=1/P(1)

plot(vm,im,'o',v,I,'LineWidth',1.0);
xlabel('Voltage (V)','FontSize',14);
ylabel('Current (mA)','FontSize',14);
```

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```
set(gca,'Fontsize',14,'LineWidth',1.0)
```

52. Utilize the fact that in the circuit of Fig. 2.39, the total power supplied by the voltage source must equal the total power absorbed by the two resistors to show that $V_{R2} = V_S\,(R_2)/(R_1 + R_2)$. You may assume the same current flows through each element (a requirement of charge conservation).

The power supplied by the voltage source is $V_s\,I$.
The power absorbed by resistor R_1 is I^2R_1.
The power absorbed by resistor R_2 is I^2R_2.

Since we know that the total power supplied is equal to the total power absorbed, we may write:

$$V_s\,I = I^2R_1 + I^2R_2$$

or

$$V_s = I\,R_1 + I\,R_2$$
$$V_s = I\,(R_1 + R_2)$$

By Ohm's law,

$$\mathrm{I} = V_{R_2} / R_2$$

so that

$$V_s = \frac{V_{R_2}}{R_2}\left(R_1 + R_2\right)$$

Solving for V_{R_2} we find

$$\boxed{V_{R_2} = V_s \frac{R_2}{\left(R_1 + R_2\right)}}$$

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53. For the circuit in Figure 2.39, suppose that the resistor R_2 represents a very sensitive and expensive piece of electronics. To ensure that the equipment is not damaged, R_1 is incorporated to represent a fuse, with a rating of 5A and resistance of 0.1 Ω. If the voltage source is 12 V, what is the lowest resistance that could be encountered as a short circuit condition for R_2 before blowing the fuse?

The fuse will blow when 5 A or more flows through the circuit.

This current will flow when there is a total resistance of (12 V)/(3 A) = 4 Ω.

The fuse has a resistance of 0.1 Ω, thus a resistance for R_2 of 3.9 Ω or less will cause the fuse to blow.

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54. For each of the circuits in Fig. 2.40, find the current I and compute the power absorbed by the resistor.

Top left:

$$i = \frac{v}{R} = \frac{5}{10 \quad 10^3} = 500 \quad 10^{\ 6} \ A = \boxed{500 \quad A}$$

$$p = vi = \left(5 \ V\right)\left(500 \quad A\right) = \boxed{2.5 \ mW}$$

Top right:

$$i = \frac{v}{R} = \frac{5}{10 \quad 10^3} = \quad 500 \quad 10^{\ 6} \ A = \boxed{500 \quad A}$$

$$p = vi = \left(\ 5 \ V\right)\left(\ 500 \quad A\right) = \boxed{2.5 \ mW}$$

Bottom left:

$$i = \frac{v}{R} = \frac{5}{10 \quad 10^3} = \quad 500 \quad 10^{\ 6} \ A = \boxed{500 \quad A}$$

$$p = vi = \left(\ 5 \ V\right)\left(\ 500 \quad A\right) = \boxed{2.5 \ mW}$$

Bottom right:

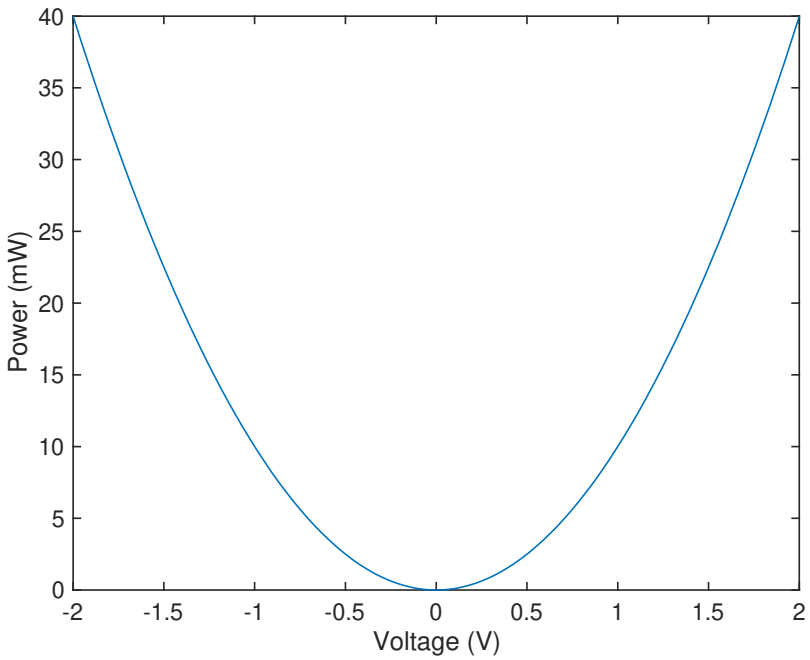
$$i = \frac{v}{R} = \frac{5}{10 \quad 10^3} = 500 \quad 10^{\ 6} \ A = \boxed{500 \quad A}$$

$$p = vi = \left(5 \ V\right)\left(500 \quad A\right) = \boxed{2.5 \ mW}$$

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55. Sketch the power absorbed by a 100 Ω resistor as a function of voltage over the range $-2\text{ V} \le V_{resistor} \le +2\text{ V}$.

$$p = vi = \frac{v^2}{R}$$




```
v = linspace(-2,2,100);
R=100;

for i = 1:100
    I(i) = v(i)/R;
    P(i)=v(i)*I(i);
end
plot(v,P*1000,'LineWidth',1.0);
xlabel('Voltage (V)','FontSize',14);
ylabel('Power (mW)','FontSize',14);
set(gca,'Fontsize',14,'LineWidth',1.0)
```

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56. You built an android that has a subcircuit containing a power supply, tactile sensor, and a fuse; where safe operation should keep current below 250 mA. You measured that your sensor is dissipating 12 W, the power supply is providing 12.2 W, and the voltage drop across the fuse is 500 mV. Is your circuit properly protected?

The fuse is dissipating $12.2 \quad 12 = 0.2\ W$ of power.

The current through the fuse (and the circuit) is $i = \frac{p}{v} = \frac{0.2}{0.5} = 0.4\ A$

The current has exceeded the safe limit of 250 mA!

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57. Using the data in Table 2.4, calculate the resistance and conductance of 50 ft of wire with the following sizes: AWG 2, AWG 14, and AWG 28.

The data in Table 2.4 provides resistance for each 1000 ft.
The shorter wire length of 50 ft will reduce resistance according to a factor of 50/1000=0.05 (conductance will increase according to a factor of 1000/50=20).

AWG 2: $R = 7.815\ \text{m}\Omega$; $G = 127.96\ \text{S}$

AWG 14: $R = 0.126\ \Omega$; $G = 7.9365\ \text{S}$

AWG 28: $R = 3.265\ \Omega$; $G = 0.30628\ \text{S}$

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58. To protect an expensive circuit component from being delivered too much power, you decide to incorporate a fast-blowing fuse into the design. Knowing that the circuit component is connected to 12 V, its minimum power consumption is 12 W, and the maximum power it can safely dissipate is 100 W, which of the three available fuse ratings should you select: 1 A, 4 A, or 10 A? Explain your answer.

The power consumption is between a minimum of 12 W and maximum of 100 W.

At 12 V, the current will range from 1 A to 8.333 A.

It would be best to choose the 4 A fuse, to ensure that the minimum power can be provided, while also ensuring that the maximum power is not exceeded.

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59. So-called "n-type" silicon has a resistivity given by $\rho = (-qN_D\mu_n) - 1$, where N_D is the volume density of phosphorus atoms (atoms/cm3), μ_n is the electron mobility ($cm^2/V \cdot s$), and $q = -1.602 \times 10^{-19}$ C is the charge of each electron. Conveniently, a relationship exists between mobility and N_D, as shown in Fig. 2.41. Assume an 8 inch diameter silicon wafer (disk) having a thickness of 300 μm. Design a 10 Ω resistor by specifying a phosphorus concentration in the range of $2 \times 10^{15}\ cm^{-3} \le N_D \le 2 \times 10^{17}\ cm^{-3}$, along with a suitable geometry (the wafer may be cut, but not thinned).

Example Design:

$$R = \frac{L}{A} = \frac{L}{Wt}$$ (where W is width of cross section, t is thickness)

Choosing a value in the middle of the range,

$N_D = 1 \quad 10^{16}\ cm^{-3}$

From the graph, $\mu_n \approx 1{,}500\ cm^2/Vs$

$$= \frac{1}{qN_D \quad _n} = \frac{1}{\left(1.602 \times 10^{-19} C\right)\left(10^{16} cm^{-3}\right)\left(1{,}500 cm^2/Vs\right)} = 0.4161 \quad cm$$

We now have all parameters except the ratio of L/W

We can solve for L/W, and then choose values (dimensions) for the resistor.

$$\frac{L}{W} = \frac{Rt}{} = \frac{(10 \quad)\left(300 \times 10^{-4} cm\right)}{0.4161 \quad cm} = 0.7210$$

Choosing a convenient dimension of

$W = 1\ mm = 1{,}000 \quad m$

$L = 721 \quad m$

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60. A 250 ft long span separates a dc power supply from a lamp which draws 25 A of current. If 14 AWG wire is used (note that two wires are needed for a total of 500 ft), calculate the amount of power wasted in the wire.

From Table 2.4, for 500 ft of 14 AWG wire

$$R = \frac{2.52}{2} = 1.26\ \Omega$$

$$P = VI = I^2R = (25A)^2\,(1.26\Omega)$$

$$\boxed{P = 787.5\ \text{W}}$$

That is a lot of power loss for a wire!

However, the value of 25 A is also very large, as well as the wire distance. In fact, most household circuits are limited to around 20 A. That is certainly not your typical desk lamp!

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61. The resistance values in Table 2.4 are calibrated for operation at 20◦C. They may be corrected for operation at other temperatures using the relationship

(a) Calculate the length of the original wire.

$$50\ \Omega = L\left(\frac{65.3\ \Omega}{1000\,ft}\right)$$

$$L = \frac{(50\ \Omega)(1000\,ft)}{65.3\ \Omega} = 765.7\ ft$$

(b) From relation, get resistance at 20 C required for 50 Ω.
First convert temperature 110.5 °F = 43.61 °C

$$R = \frac{50(234.5+20)}{(234.5+43.61)} = 45.76\ \Omega$$

The required length is

$$L = \frac{(45.76\ \Omega)(1000\,ft)}{65.3\ \Omega} = 700.8\ ft$$

The wire should be shortened 765.7−700.8 = 64.9 ft

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62. Your favorite meter contains a precision (1% tolerance) 10 Ω resistor. Unfortunately, the last person who borrowed this meter somehow blew the resistor, and it needs to be replaced. Design a suitable replacement, assuming at least 1000 ft of each of the wire gauges listed in Table 2.4 is readily available to you.

We require a 10 Ω resistor, and since it is for a meter, it implies that size, weight or both would be important to consider when selecting a wire gauge. We have 1,000 ft of each of the gauges listed in Table 2.4 with which to work. Using 28-AWG wire, the narrowest available, would require

(10 Ω) / (65.3 Ω/1000ft) = 153 ft

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63. If 1 mA of current is forced through a 1 mm diameter, 2.3 meter long piece of hard, round, aluminum-clad steel (B415) wire, how much power is wasted as a result of resistive losses? If instead wire of the same dimensions but conforming to B75 specifications is used, by how much will the power wasted due to resistive losses be reduced?

$$R = \frac{\rho L}{A}$$

$$A = \pi r^2 = \pi\left(\frac{D}{2}\right)^2 = \pi\left(\frac{0.001m}{2}\right)^2 = 7.854\times10^{-7}\,m^2$$

$$R = \frac{\rho L}{A} = \frac{\left(8.4805\times10^{-6}\times10^{-2}\,\Omega\cdot m\right)\left(2.3m\right)}{\left(7.854\times10^{-7}\,m^2\right)} = 248.35\times10^{-3}\ \Omega$$

$$P = I^2R = \left(0.001\right)^2\left(0.24835\right) = 248.35\times10^{-9}\ W = \boxed{248.35\ nW}$$

Using B75 will reduce resistance, where power losses will scale with resistivity.

$$\frac{P_{B75}}{P_{B415}} = \frac{\rho_{B75}}{\rho_{B415}} = \frac{1.7241}{8.4805} = 0.2033$$

$$P_{B75} = \left(0.2033\right)\left(248.35nW\right) = 50.49nW$$

The power wasted will reduce by 197.86 nW, or by 79.67%

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64. The network shown in Fig. 2.42 can be used to accurately model the behavior of a bipolar junction transistor provided that it is operating in the forward active mode. The parameter β is known as the current gain. If for this device β = 100, and I_B is determined to be 100 μA, calculate

(a) $I_C = \beta I_B = (100)(100\mu A) = 10\times10^{-3}\,A = \boxed{10mA}$

(b) $P = I_B V_{Base-Emitter} = (100\times10^{-6})(0.7) = 70\times10^{-6}W = \boxed{70\mu W}$

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65. A 100 W tungsten filament light bulb functions by taking advantage of resistive losses in the filament, absorbing 100 joules each second of energy from the wall socket. How much optical energy per second do you expect it to produce, and does this violate the principle of energy conservation?

Take the maximum efficiency of a tungsten lightbulb as 10%. Then only ~10 W (or 10 J/s) of optical (visible) power is expected. The remainder is emitted as heat and invisible light.

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66. An LED operates at a current of 40 mA, with a forward voltage of 2.4 V. You construct a series circuit shown below to power the LED using two 1.5 V batteries, each with a capacity of 2000 mAh. Determine the required value of the resistor, and how long the circuit will operate before the batteries run out of energy.

The series connection of the batteries will provide 3 V
The LED runs at 2.4 V
The voltage drop across the resistor will be 0.6 V
The current through the circuit is 0.04 A
Resistance required is V/I = 0.6/0.04 = 15 Ω

The batteries will each provide power to the circuit, and each have the same current of 40 mA flowing through it. The battery will run for a time

$$t = \frac{2000mAh}{40mA} = 50h$$

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67. You have found a way to directly power your wall clock (consumes 0.5 mW of power) using a solar cell collecting ambient room light, rather than using an AA battery. The solar cell and battery each provide the required voltage of 1.5V, and the proper current for clock operation. Your solar cell has an efficiency of 15% and costs $6, and each AA battery has a capacity of 1200 mAh and costs $1. What is the payback time (point in time where the cost of solar cell would match the cost for supplying batteries) for using a solar cell instead of batteries?

Payback time will be when the cost of batteries used meets and exceeds the cost of the solar cell. This will occur at six batteries.

Six batteries have a capacity of $6 \times 1200 = 7{,}200$ mAh

From power consumption of 0.5 mW, current flow is $I = P/V = 0.5\text{mW}/1.5\text{V} = 0.3333$ mA

Batteries would run for $t = 7{,}200\text{ mAh} / 0.3333\text{ mA} = 21{,}600$ h

Time of 21,600 hours = 900 days = 2.47 years

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