1. Convert the following to engineering notation:

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

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

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

(d) 39,212 as $= 3.9212 \times 10^{4} \times 10^{-18} = 39.212 \times 10^{-15}$ s $=$ $\boxed{39.212 \text{ fs}}$

(e) $\boxed{3\ \Omega}$

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

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

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

2. Convert the following to engineering notation:

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

(b) $0.0001\ \text{decimeter} = 1 \times 10^{-4} \times 10^{-1} = 10 \times 10^{-6}\ m = \boxed{10\ \mu\text{m}}$

(c) $1400\ \text{mK} = 1.4 \times 10^{3} \times 10^{-3} = \boxed{1.4\ K}$

(d) $32\ \text{nm} = 32 \times 10^{-9} m = \boxed{32\ \text{nm}}$

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

(f) $2021\ \text{micromoles} = 2.021 \times 10^{3} \times 10^{-6} = 2.021 \times 10^{-3} moles = \boxed{2.021\ \text{millimoles}}$

(g) $13\ \text{deciliters} = 13 \times 10^{-1} = \boxed{1.3\ liters}$

(h) $1\ \text{hectometer} = \boxed{100\ meters}$

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 $= 1 \times 10^{3} \times 10^{-24} = 1 \times 10^{-21}$ *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 $= 10 \times 10^{-6}$ *seconds* = 10 μs

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

4. Expand the following distances in simple meters:

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

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

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

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

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

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

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

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)

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

(or, 913.24 femto-galactic-years!)

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.

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

(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.

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

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?

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

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

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.

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

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

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.

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

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

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

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

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

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

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.

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.

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.

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

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

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

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

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

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

(a) 9 C

(b) −1 C

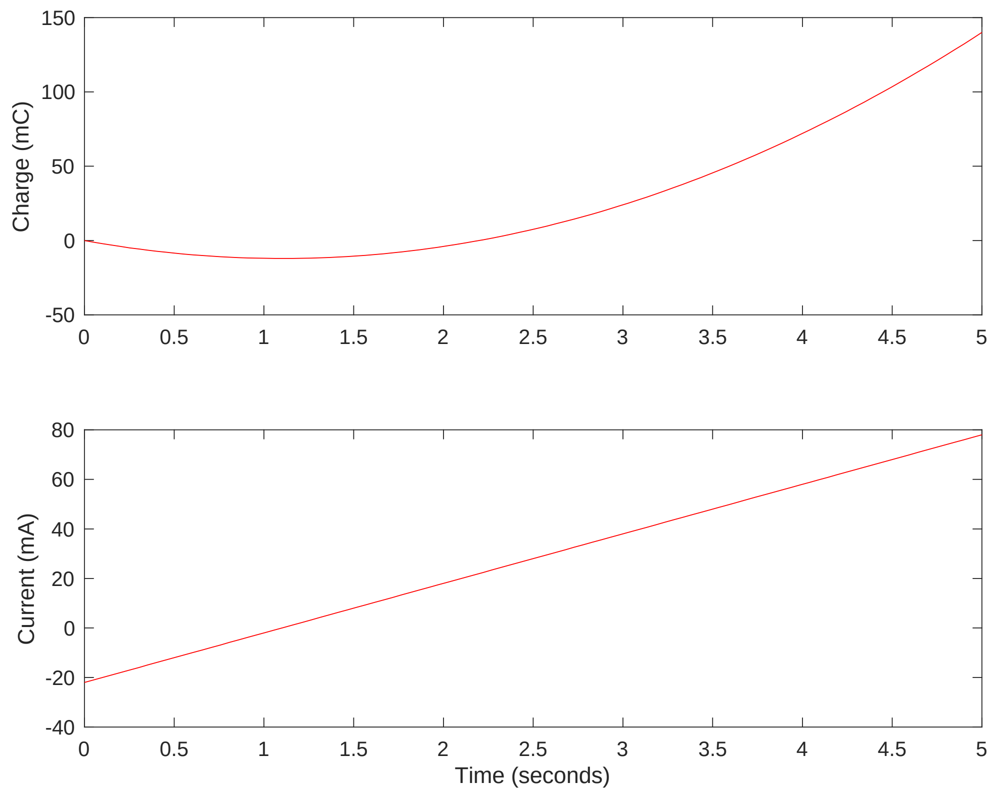
(c) $i = \frac{dq}{dt} = -10\frac{C}{s} = -10\ A$, The current is constant (time independent)

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

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

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

(b) Sketch q(t) and i (t) over the interval $0 \leq t < 5$ 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)')
```

```
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?

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

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.

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

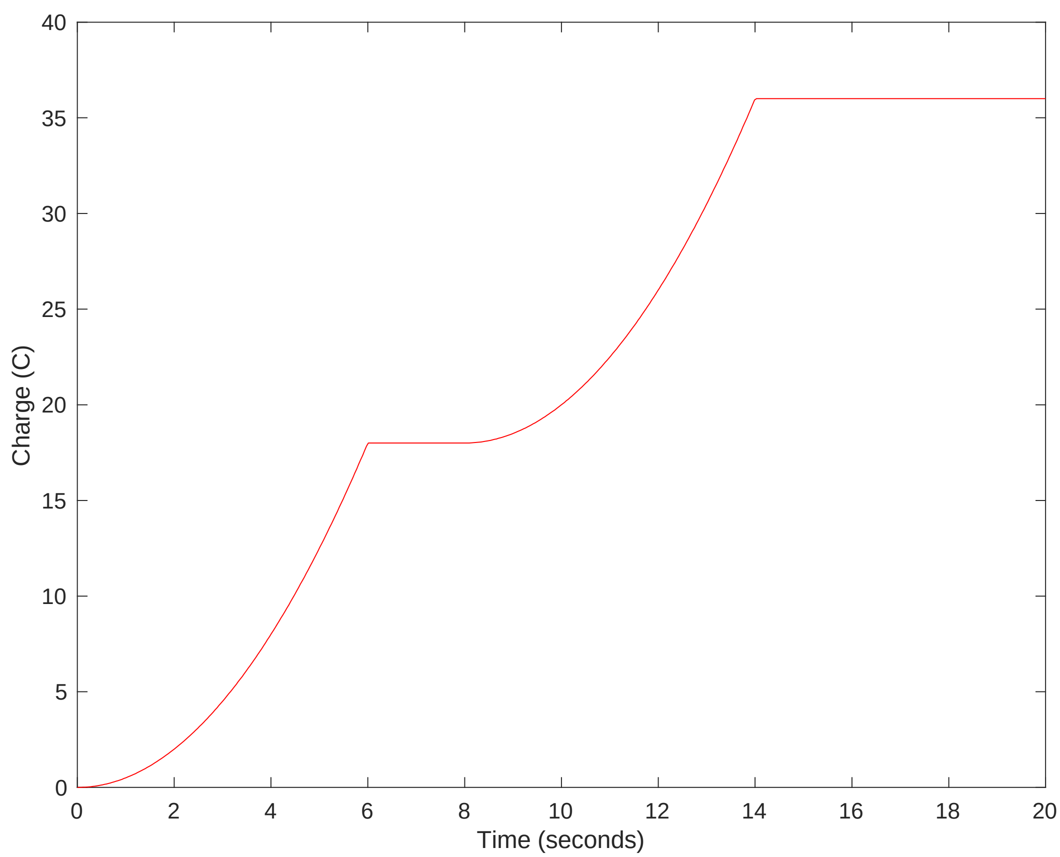
(a) The average value is the integral of the function divided by the time period.

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

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

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

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



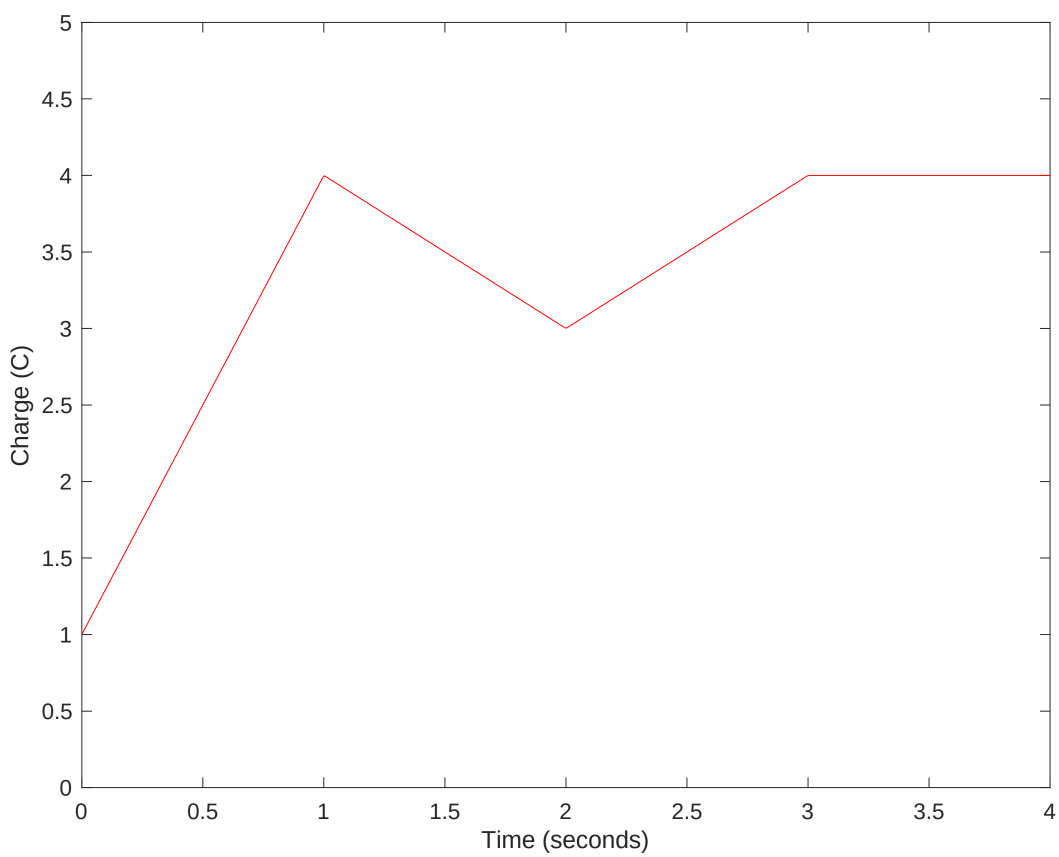
21. The current waveform depicted in Fig. 2.29 is characterized by a period of 4 s.

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

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

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

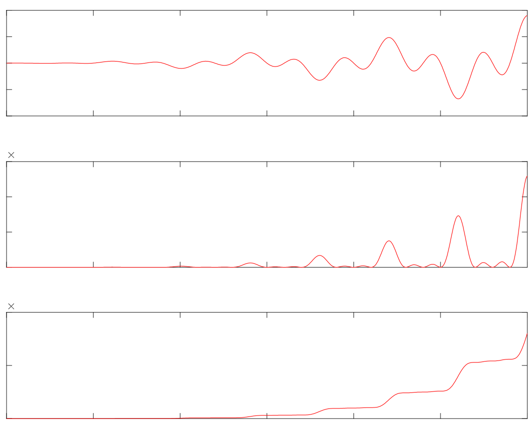
$$q(t) = \int i(t)dt = \begin{cases} 3t + q(0) = 3t + 1\ \text{C}, & 0 \le t \le 1\ \text{s} \\ -t + 1 + q(1) = -t + 5\ \text{C}, & 1 \le t \le 2\ \text{s} \\ t - 2 + q(2) = t + 1\ \text{C}, & 2 \le t \le 3\ \text{s} \\ q(3) = 4\ \text{C}, & 3 \le t \le 4\ \text{s} \end{cases}$$



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.

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

From calculations, $w(t=60\text{ s}) = 801.87\times10^6$ 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)')
```

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 .

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

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

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.

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)

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

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

(a)

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

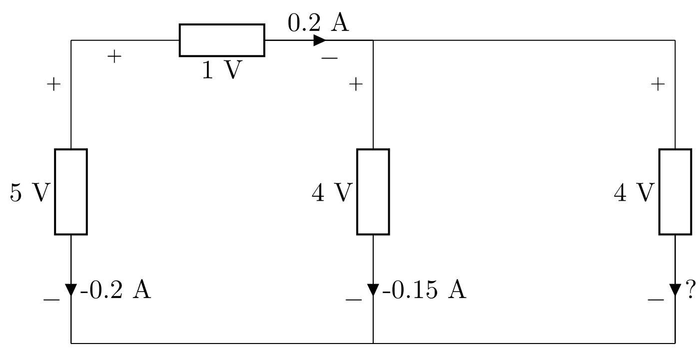
(b)

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

(c)

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

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: $p = vi = (5\ V)(-0.2\ A) = \boxed{-1\ W\ (supplies\ 1\ W)}$

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

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

4 V element on right: since total power must sum to zero, must be absorbing 1.4 W
$I = 0.35$ A

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.

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

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

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 » $(0.375\ V)(2.5\ A)$ » $0.94\ W$