Chapter 2
Circuit elements

Exercises

Ex. 2.3-1

$$\text{If } v_1 = \frac{di_1}{dt} \text{ and } v_2 = \frac{di_2}{dt} \text{ then } v_1 + v_2 = \frac{di_1}{dt} + \frac{di_2}{dt} = \frac{d}{dt}(i_1 + i_2)$$

thus satisfying the property of superposition.

Since $v_1 = \frac{di_1}{dt}$ and for ki_1 we get $\frac{d}{dt}(ki_1) = k\frac{di_1}{dt}$, thus the property of homogeneity is also satisfied. Thus the element is linear.

Ex. 2.3-2

Consider homogeneity only.
For i < 0 an excitation, i, yields v = 0 and an excitation, Ki, yields v = 0 as well.
Since the response, v, does not scale in the manner of the excitation, i, the property of homogeneity is not satisfied.

Ex. 2.3-3 a) $v = \left(\frac{2.5}{1}\right)i$ for $-1 < i < 1$

b) $v = \left(\frac{-2}{1.5}\right)i = \frac{-4}{3}\, i = -1.333i$ for $-1.5 < i < 1.5$

Ex. 2.5-1

$$P = \frac{v^2}{R} = \frac{(10v)^2}{100\Omega} = 1\text{ W}$$

Ex. 2.5-2

$$P = \frac{v^2}{R} = \frac{(10\cos t)^2}{10} = 10\cos^2 t\text{ W}$$

Ex. 2.8-1

$i_c = -1.2\text{A},\ v_d = 24\text{V}$

$i_d = 4(-1.2) = -4.8\text{A}$

$P = vi = (24)(-4.8\text{A}) = -115.2\text{ W absorbed}$

Ex. 2.8-2

$v_c = 2\text{V},\ i_d = 1.5\text{ A}$

$v_d = 2(2) = 4\text{V}$

$P = vi = (4\text{V})(1.5\text{A}) = 6\text{ W absorbed}$

Ex. 2.8-3

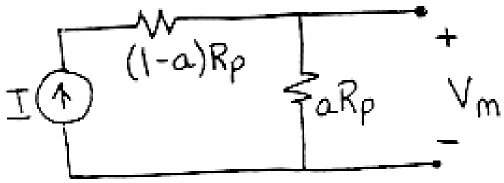
$i_c = 1.25\text{A},\ i_d = 1.75\text{A}$

$v_d = 2(1.25) = 2.5\text{ V}$

$P = vi = (2.5\text{V})(1.75\text{A}) = 4.375\text{ W absorbed}$

Ex. 2.9-1

$\theta = 45^\circ,\ I = 2mA,\ R_p = 20k\Omega$



where $a = \dfrac{\theta}{360} \Rightarrow aR_p = \dfrac{45}{360}(20k\Omega) = 2.5k\Omega$

$v = iR$

$v_m = (2mA)(2.5k\Omega) = \underline{5V}$

Ex. 2.9-2 $v = 10V,\ i = 280\mu A,\ k = 1\dfrac{\mu A}{^\circ K}$ for AD590

$i = kT$

$T = i/K = (280\mu A)\left(1\dfrac{^\circ K}{\mu A}\right) = \underline{280^\circ\ K}$

Ex. 2.10-1 t = 1s (switch closed)

$i = v/R = 12V/3k\Omega = \underline{4mA}$

t = 5 (switch open) $\underline{i = 0A}$

Ex. 2.10-2 t = 4s (both switches open)

$\underline{i = 0}$

Ex. 2.10-3 t = 4s (switch up)

$v = iR = (2mA)(3k\Omega) = \underline{6V}$

t = 6s (switch down)

$\underline{v = 0}$

Ex. 2.10-4 t = ls (switch up)

$i = v/R = (6V)/(3k\Omega) = \underline{2mA}$

t = 3s (*s*witch up)

$i = v/R = (12V)/(3k\Omega) = \underline{4mA}$

Problems

Section 2-3 Engineering and Linear Models

P 2.3-1 The element is not linear. For example, doubling the current from 2 A to 4 A does not double the voltage. Hence, the property of homogeneity is not satisfied.

P 2.3-2 Plotting *v* versus *i* using the given data produces a straight line with a slope equal to 16 V/A. This straight line passes through the origin. The equation of the line is $v = 16i$. Such a relationship was shown to be linear in Example 2.3-1.

P 2.3-3 (a) The data points do indeed lie on a straight line. The slope of the line is 120 V/A and the line passes through the origin so the equation of the line is $v = 120i$. The element is indeed linear.

(b) When i = 40 mA, v = (120 V/A)×(40 mA) = (120 V/A)×(0.04 A) = 4.8 V

(c) When v = 4 V, $i = \frac{4}{120} = 0.033$ A = 33 mA.

P 2.3-4 (a) The data points do indeed lie on a straight line. The slope of the line is 256.5 V/A and the line passes through the origin so the equation of the line is $v = 256.5i$. The element is indeed linear.

(b) When i = 4 mA, v = (256.5 V/A)×(4 mA) = (256.5 V/A)×(0.004 A) = 1.026 V

(c) When v = 12 V, $i = \frac{12}{256.5} = 0.04678$ A = 46.78 mA.

P2.3-5

$v = \sqrt{i}$

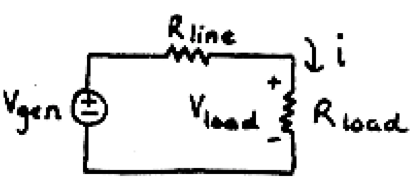
$v^2 = i$

Element is not linear

P 2.3-6 Let i = 1 A , then v = 3i + 5 = 8 V. Next 2i = 2A but 16 = 2v ≠ 3(2i) + 5 = 11. . Hence, the property of homogeneity is not satisfied. The element is not linear.

P2.3-7

a)



b)

$$\text{efficiency} = \frac{p_{load}}{p_{gen}}$$

$$\text{now } P_{load} = \frac{v_{load}^2}{R_{load}} \Rightarrow R_{load} = \frac{(9\times 10^5)^2}{1.2\times10^9\,\text{W}} = 675\Omega$$

$$\therefore i = \frac{v_{load}}{R_{load}} = \frac{9\times10^5}{675} = 1.33\times10^3 \text{ A}$$

$$\therefore P_{gen} = v_{gen}\, i = (9.5\times10^5)(1.33\times10^3) = 1.27\times10^9\,\text{W}$$

$$\therefore \text{efficiency} = \frac{P_{load}}{P_{gen}} = \frac{1.2\text{ GW}}{1.27\text{ GW}} = \underline{0.945}$$

c) lost power goes to the resistance in power lines

d) $W = P\Delta t = (1.2\times10^9 \text{ W})(24\text{hr})(3600\ {}^{s}/_{hr}) = \underline{1.04\times10^{14}\text{J}}$

P2.3-8 Charging power to battery: $P = 12(2.8A) = \underline{33.6 \text{ W}}$

total power to charging source: $P_c = (14.52) \times 2.8 = \underline{40.66 \text{ W}}$

total power to battery: $P_b = (12.0 + 1.68) \times 2.8 = \underline{38.3 \text{ W}}$

total power lost in charger: $P_l = .84\ (2.8) = \underline{2.352 \text{ W}}$

now $2.8(12+1.68+.84) = 2.8(14.52)$

so power from source = total power absorbed by 3 elements

need 3360 C of charge

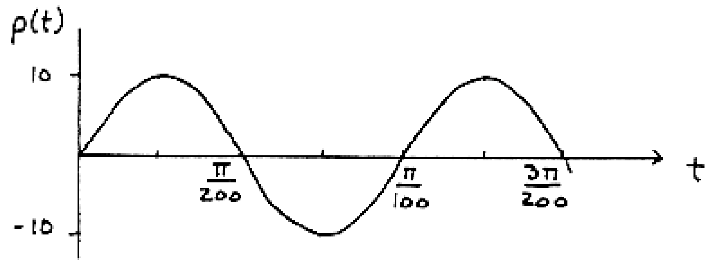
$$i = \frac{\Delta q}{\Delta t} \text{ or } \Delta t = \frac{\Delta q}{i} = \frac{3360}{2.8} = 1200\text{s} = \underline{20 \text{ minutes}}$$

Section 2-4 Active and Passive Circuit Elements

P2.4-1

a) $P(t) = vi = (10 \sin 100\,t)(2 \cos 100\,t \text{ mA})$

$= 20 \sin 100\,t \cos 100\,t = \underline{10 \sin 200\,t}$ mW



b) power absorbed for $\frac{2n\pi}{200} < t < \frac{(2n+1)\pi}{200}$ $n = 0,1,2\ldots$

power delivered for $\frac{(2n-1)\pi}{200} < t < \frac{2n\pi}{200}$ $n = 1,2,3\ldots$

P2.4-2

$$P = vi = \left(2\frac{d}{dt}(2 \sin t)\right)(2 \sin t)$$

$$= (4 \cos t)(2 \sin t) = 8 \cos t \sin t \qquad t > 0$$

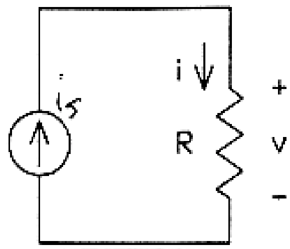
$$W = \int_0^t P\,dt = 8\int_0^t \cos t \sin t\,dt$$

$$= \frac{8}{2}\sin^2 t\Big|_0^t = 4\sin^2 t > 0$$

$\therefore$ <u>element is passive</u>

Section 2-5   Resistors

P2.5-1

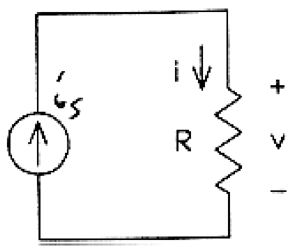


$i = i_s = 3A$ and $v = Ri = 7 \times 3 = \underline{21v}$

v and i adhere to the passive convention

$\therefore P = vi = 21 \times 3 = \underline{63\ W}$ is the power absorbed by the resistor.

P2.5-2

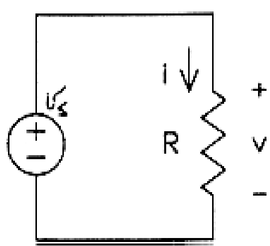


$i = i_s = 3mA$ and $v = 24$ V

$$R = \frac{v}{i} = \frac{24}{.003} = 8000 = \underline{8\ K\Omega}$$

$$P = (3\times10^{-3})\times24 = 72\times10^{-3} = \underline{72\ mW}$$

P2.5-3



$v = v_s = 10V$ and $R = 5\Omega$

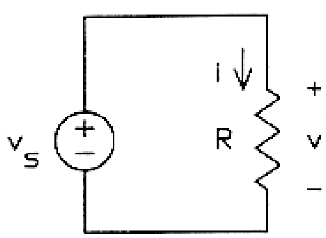
$$i = \frac{v}{R} = \frac{10V}{5\Omega} = \underline{2A}$$

v and i adhere to the passive convention

$\therefore\ p = vi = 2A\cdot10V = \underline{20\ W}$

is the power absorbed by the resistor

P2.5-4

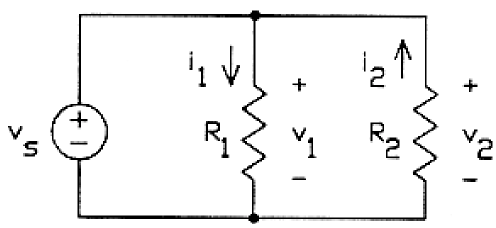


$v = v_s = 24V$ and $i = 2A$

$$R = \frac{v}{i} = \frac{24V}{2A} = \underline{12\Omega}$$

$p = vi = 24\cdot2 = \underline{48\ W}$

P2.5-5



$v_1 = v_2 = v_s = 150V;\ R_1 = 50\Omega;\ R_2 = 25\Omega$

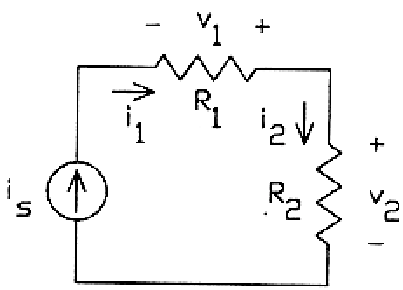
v_1 and i_1 adhere to the passive convention so $i_1 = \frac{v_1}{R_1} = \frac{150}{50} = \underline{3A}$

$$v_2 \text{ and } i_2 \text{ do not adhere to the passive convention so } i_2 = -\frac{v_2}{R_2} = -\frac{160}{25} = \underline{-6A}$$

The power absorbed by R_1 is $P_1 = v_1 i_1 = 150 \cdot 3 = \underline{450W}$

The power absorbed by R_2 is $P_2 = -v_2 i_2 = -150(-6) = \underline{900W}$

P2.5-6



$i_1 = i_2 = i_s = 2A$; $R_1 = 4\Omega$ and $R_2 = 8\Omega$

v_1 and i_1 do <u>not</u> adhere to the passive convention so $v_1 = -R_1\ i_1 = -4 \cdot 2 = \underline{-8V.}$

The power absorbed by R_1 is $P_1 = -v_1 i_1 = -(-8)(2) = \underline{16\ W.}$

v_2 and i_2 do adhere to the passive convention so $v_2 = R_2\ i_2 = 8 \cdot 2 = \underline{12V}$.

The power absorbed by R_2 is $P_2 = v_2 i_2 = 12 \cdot 2 = \underline{24\ W.}$

P2.5-7

Model the heater as a resistor, then from $P = \frac{v^2}{R} \Rightarrow R = \frac{v^2}{P} = \frac{(250)^2}{1000} = \underline{62.5\Omega}$

with a 210 V source $\quad P = \frac{v^2}{R} = \frac{(210)^2}{62.5} = \underline{705.6\ W}$

P2.5-8

The current required by the mine lights is: $i = \frac{P}{v} = \frac{5000}{120} = 125/3$ A

Power loss in the wire is : i^2 R

Thus the resistance of the copper wire is

$$R = \frac{0.05P}{i^2} = \frac{0.05 \times 5000}{(125/3)^2} = 0.144\ \Omega$$

now since the length of the wire is

$$L = 2 \times 100 = 200m$$

thus $R = PL/A$ with $P = 1.7 \times 10^{-6}\,\Omega \cdot \text{cm}$ from table 2−1

$$\Rightarrow A = \frac{PL}{R} = \frac{1.7 \times 10^{-6} \times 20{,}000}{0.144} = \underline{0.236\text{cm}^2}$$

Section 2-6 Independent Sources

P2.6-1 (a) $i = \frac{v_s}{R} = \frac{15}{5} = \underline{3A}$

$P = Ri^2 = 5(3^2) = \underline{45\ W}$

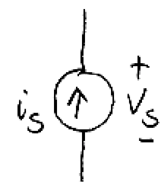
(b) i and P do not depend on i_s. The values of i and P are 3A and 45W both when i_s = 3A and when i_s =5A.

P2.6-2 (a) $v = R\, i_s = 5 \cdot 2 = \underline{10V}$

$P = \frac{v^2}{R} = \frac{10^2}{5} = \underline{20\ W}$

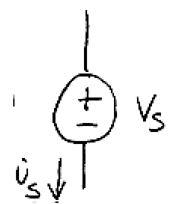
(b) v and P do not depend on V_s. The values of v and P are 10V and 20 W both when v_s =10V and when v_s =5V

P2.6-3



Consider the current source. i_s and v_s do not adhere to the passive convention,

so $P_{cs} = i_s v_s = 3 \cdot 12 = \underline{36\ W}$ is the power supplied by the current source.

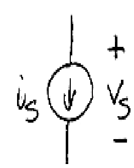


Consider the voltage source. i_s and v_s do adhere to the passive convention,

so $P_{vs} = i_s\, v_s = 3 \cdot 12 = \underline{36\ W}$ is the power absorbed by the voltage source.

$\therefore$ The voltage source supplies −36 W.

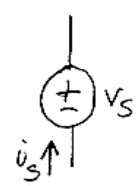
P2.6-4



Consider the current source. i_s and v_s adhere to the passive convention

so $P_{cs} = i_s v_s = 3 \cdot 12 = \underline{36\ W}$ is the power absorbed by the current source.

Current source supplies −36W.



Consider the voltage source. i_s and v_s do not adhere to the passive convention

so $P_{vs} = i_s v_s = 3 \cdot 12 = \underline{36\ W}$ is the power supplied by the voltage source.

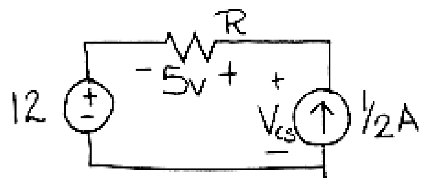
P2.6-5 a) $P = vi = (2 \cos t)(10 \cos t) = \underline{20 \cos^2 t\ mW}$

b) $W = \int_0^1 P\, dt = \int_0^1 20 \cos^2 t\, dt$

$$= 20\left(\frac{1}{2}t + \frac{1}{4}\sin 2t\right)\Big|_0^1 = \underline{10 + 5 \sin 2\ mJ}$$

Section 2-7 Voltmeters and Ammeters

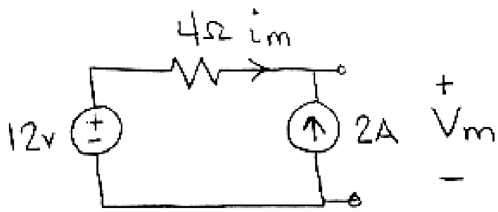
P2.7-1



(a) $R = {}^{v}\!/_{i} = \dfrac{5\text{ V}}{.5\text{ A}} = \underline{10\ \Omega}$

(b) The voltage, 12V, and current, 0.5 A, of the voltage source adhere to the passive convention. So P = 12(0.5) = 6 W is the power absorbed by the voltage source. The voltage source delivers -6 W.

P2.7-2



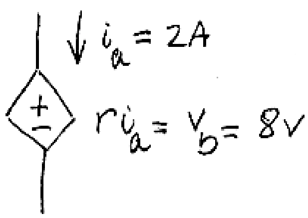
$\underline{i_m = -2\text{A}}$

i_m and v_m adhere to the passive convention so

$i_m \cdot v_m = -40$ W $\Rightarrow$ $\underline{v_m = 20\text{V}}$

Section 2-8 Dependent Sources

P2.8-1



$r = \dfrac{v_b}{i_a} = \dfrac{8\text{V}}{2\text{A}} = \underline{4\Omega}$

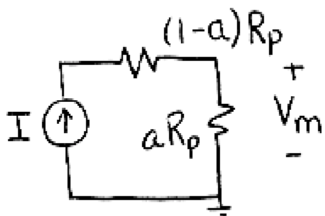
P2.8-2 $v_b = 8\text{V}\ ;\ \ g v_b = i_a = 2\text{A}\ ;\ \ g = \dfrac{i_a}{v_b} = \dfrac{2\text{A}}{8\text{V}} = \underline{0.25\dfrac{\text{A}}{\text{V}}}$

P2.8-3 $i_b = 8\text{A}\ ;\ \ d i_b = i_a = 32\text{A}\ ;\ \ d = \dfrac{i_a}{i_b} = \dfrac{32\text{A}}{8\text{A}} = \underline{4\dfrac{\text{A}}{\text{A}}}$

P2.8-4 $v_a = 2\text{V}\ ;\ \ b v_a = v_b = 8\text{V}\ ;\ \ b = \dfrac{v_b}{v_a} = \dfrac{8\text{V}}{2\text{V}} = \underline{4\dfrac{\text{V}}{\text{V}}}$

Section 2-9 Transducers

P2.9-1



$a = \dfrac{\theta}{360}\ ,\quad \theta = \dfrac{360\, v_m}{R_p i}$

$\theta = \dfrac{(360)(23\text{V})}{(100\text{k}\Omega)(1.1\text{mA})} = \underline{75.27^{\circ}}$

P2.9-2

AD590 : $K = 1\frac{\mu A}{^\circ K}$, V = 20V (voltage condition satisfied)

$4\ \mu A < i < 13\mu A$

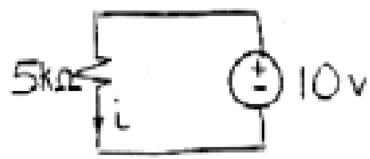
$T = i/k$

$\underline{4^\circ K < T < 13^\circ K}$

Section 2-10 Switches

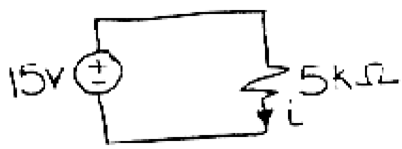
P2.10-1

t = 1s



$i = v/R = \frac{10V}{5k\Omega} = \underline{2mA}$

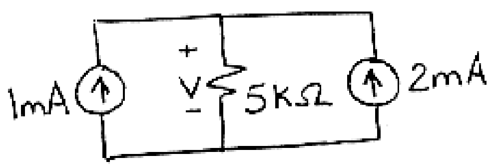
t = 4s



$i = v/R = \frac{15V}{5k\Omega} = \underline{3mA}$

P2.10-2

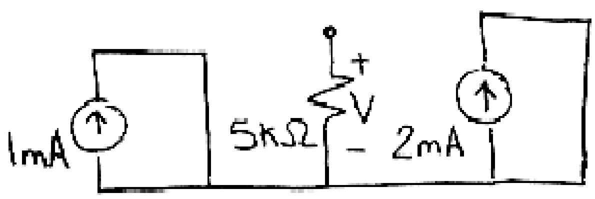
t = 1s



$v = iR = (3mA)(5k\Omega)$

$\underline{v = 15V}$

t = 4s



$\underline{V = 0}$

Verification Problems

VP 2-1 $v_0 = 40$ and $i_s = -(-2) = 2$. (Notice that the ammeter measures $-i_s$ rather than i_s.) So

$$\frac{v_0}{i_s} = \frac{40\text{V}}{2\text{A}} = 20\frac{\text{V}}{\text{A}}$$

Your lab partner is wrong.

VP 2-2 We expect the resistor current to be $i = \frac{v_s}{R} = \frac{12\text{V}}{25\Omega} = 0.48\text{A}$. The Power absorbed by this resistor will be $P = iv_s = (0.48\text{A})\,(12\text{V}) = 5.76\text{W}$ A half watt resistor can't absorb this much power. You should not try another resistor.

Design Problems

DP 2-1:

1.) $\frac{10}{R} > 0.04 \quad \Rightarrow \quad R < \frac{10}{0.04} = 250\,\Omega$

2.) $\frac{10^2}{R} < \frac{1}{2} \quad \Rightarrow \quad R > 200\,\Omega$

Therefore 200 < R < 250 Ω. For example, R = 225 Ω.

DP 2-2:

1.) $2R > 40 \quad \Rightarrow \quad R > 20\,\Omega$

2.) $2^2 R < 15 \quad \Rightarrow \quad R < \frac{15}{4} = 3.75\,\Omega$

Therefore 20 < R < 3.75 Ω. These conditions cannot satisfied simultaneously.

DP 2-3:

$$P_1 = (10\,mA)^2 \cdot (1000\,\Omega) = (.01)^2 (1000) = 0.1\,W < \frac{1}{8}\,W$$

$$P_2 = (10\,mA)^2 \cdot (2000\,\Omega) = (.01)^2 (2000) = 0.2\,W < \frac{1}{4}\,W$$

$$P_3 = (10\,mA)^2 \cdot (4000\,\Omega) = (.01)^2 (4000) = 0.4\,W < \frac{1}{2}\,W$$