Solutions Manual to accompany Millman

MICROELECTRONICS

Digital and Analog Circuits and System

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McGraw-Hill

CHAPTER 1

1-1 (a) From Eq. (1-6) for an accelerating potential $V_d = -V$, $\frac{1}{2}mv_o^2 = \frac{1}{2}mv^2 - qV$. For $v_o = 0$ we have

$$V = mv^2/2q = \frac{9.11\times10^{-31}\times(1.88\times10^7)^2}{2\times(1.60\times10^{-19})} = \underline{1006\text{ V}}$$

(b) Eq. (1-6) gives for a positive charge and a negative potential V: $\frac{1}{2}m'v^2 = \frac{1}{2}mv^2 + qV$

From Appendix A, $m' = 2.01\times1.66\times10^{-27}$
$= 3.337\times10^{-27}$kg.

$$v = \sqrt{v_o^2 + \frac{2qV}{m'}} = \sqrt{10^{10} + \frac{2\times1.60\times10^{-19}\times1006}{3.337\times10^{-27}}} = \underline{3.27\times10^5\text{ m/s}}$$

1-2 (a) Since $1\text{eV} = 1.60\times10^{-19}$J, the initial energy of the electron in eV is $10^{-17}/1.60\times10^{-19} = \underline{62.5\text{eV}}$. Since the retarding potential is -65V, the electron will not reach the second plate.

(b) $\underline{62.5\text{V}}$

1-3 (a) Let $v_o = 0$ in Eq. (1-6) to obtain:

$$\frac{1}{2}mv_x^2 = qV_a \quad\text{or}\quad v_x = \sqrt{\frac{2qV_a}{m}}$$

(b) As soon as the electron enters the vertical field of the parallel plates P_1P_2 it is accelerated upward with a constant acceleration a_y, which is found as follows:

$$ma_y = q\mathcal{E}_y = q\frac{V_p}{d} \quad\text{or}\quad a_y = \frac{qV_p}{md}$$

Therefore, its velocity upon leaving the plates P_1P_2 is

$$v_y = a_y t_p$$

where t_p is the time for crossing the plates i.e.

$$t_p = \ell_d/v_x$$

From the above equations, $v_y = \dfrac{qV_p\ell_d}{mdv_x}$

(c) $d_s = y_p + y_s$ where y_p and y_s are the distances in the y-direction traveled at the end of t_p and t_s(=time it takes an electron to hit the screen after exiting from the plates P_1P_2), respectively.

$$d_s = \frac{1}{2}a_y t_y^2 + v_y t_s = \frac{1}{2}\left(\frac{qV_p}{md}\right)\left(\frac{\ell_d}{v_x}\right)^2 + \left(\frac{qV_p\ell_d}{mdv_x}\right)\left(\frac{\ell_s - \ell_d/2}{v_x}\right)$$

$$d_s = \frac{1}{v_x^2}\frac{qV_p}{md}\left[\frac{1}{2}\ell_d^2 + \ell_d(\ell_s - \ell_d/2)\right] = \frac{1}{v_x^2}\frac{qV_p}{md}\ell_d\ell_s$$

Substituting for v_x the expression found in part (a) we get

$$d_s = \frac{m}{2qV_a}\frac{qV_p}{md}\ell_d\ell_s = \frac{1}{2}\frac{\ell_d\ell_s}{d}\frac{V_p}{V_a}$$

(d) $$v_x = \sqrt{\frac{2\times1.60\times10^{-19}\times1000}{9.11\times10^{-31}}} = \sqrt{3.513\times10^{14}} = \underline{1.874\times10^7\text{ m/s}}$$

$$v_y = \frac{qV_p\ell_d}{mdv_x} = \frac{1.60\times10^{-19}\times100\times1.27\times10^{-2}}{9.11\times10^{-31}\times0.5\times10^{-2}\times1.874\times10^7}$$

$$= \underline{2.38\times10^6\text{ m/s}}$$

$$d_s = \frac{1}{2}\times\frac{1.27\times20}{0.5}\times\frac{100}{1000} = \underline{2.54\text{ cm}}$$

(e) Since, from part (c), V_a is inversely proportional to d_s then $V_a = \frac{2.54}{5}\times1000 = \underline{508\text{ V}}$

1-4

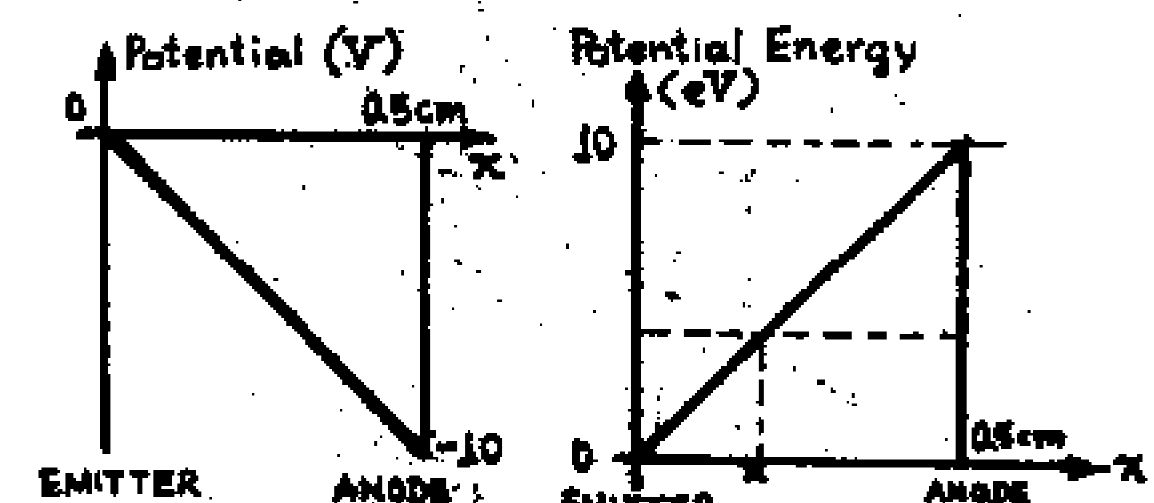

FIG 1a FIG 1b

(a) Total energy of electron at the emitter = W_E, where

$$W_E = \frac{1}{2}mv_o^2 + qV = \frac{1}{2}9.11\times10^{-31}\times10^{12} + 0$$

$$= 4.555\times10^{-19}\text{J} = \frac{4.555\times10^{-19}}{1.6\times10^{-19}}\text{ eV} = \underline{2.85\text{eV}}$$

We have

$$\frac{x}{0.5} = \frac{2.85}{10} \quad\text{or}\quad x = \frac{2.85}{10}\times0.5 = \underline{0.143\text{ cm}}$$

(b) The electron must have $W_E = 10\text{eV} = 10\times1.6\times10^{-19}$J
$= 1.6\times10^{-18}$J

$$W_E = \frac{1}{2}mv_o^2 + qV = \frac{1}{2}mv_o^2 \quad\text{or}$$

$$v_o = \sqrt{\frac{2W_E}{m}} = \sqrt{\frac{2\times1.6\times10^{-18}}{9.11\times10^{-31}}} = \underline{1.874\times10^6\text{ m/s}}$$

1-5

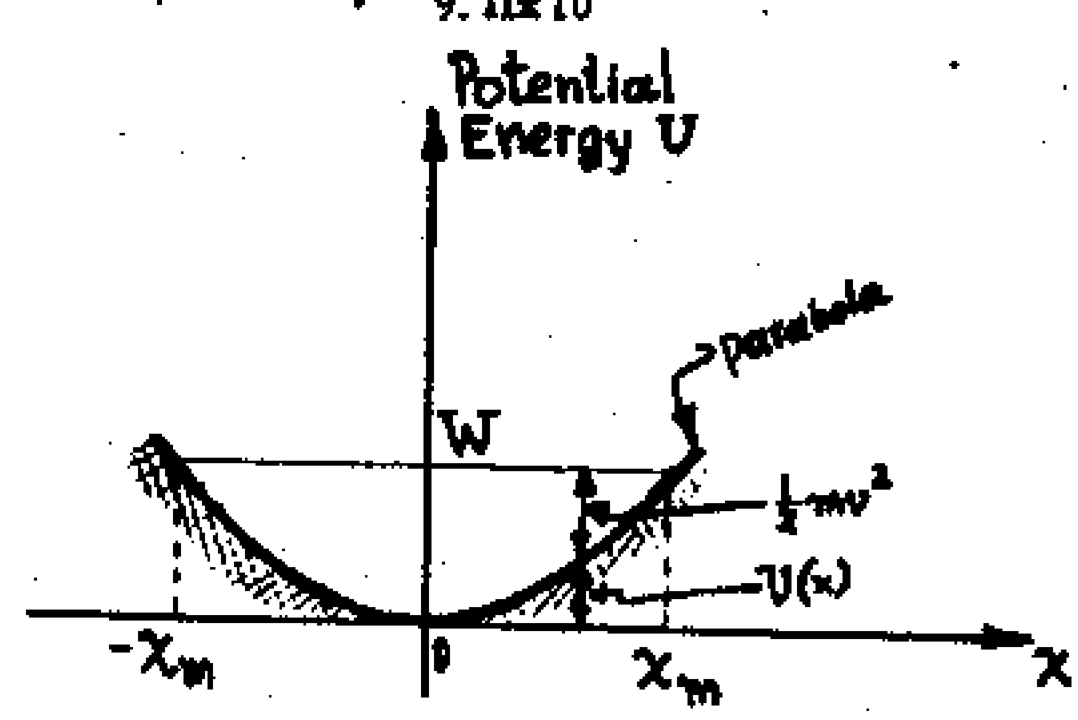

FIG 2

The potential energy as a function of x is given by

$$U(x) = -\int_0^x f(z)dz = \int_0^x kzdz = \frac{1}{2}kx^2$$

and it is shown in Fig. 2.

If we let W be the total energy we have $W = \frac{1}{2}mv^2 + U = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$ as shown in Fig. 2.

The maximum displacement x_m occurs when $v=0$ or $x_m = \sqrt{\frac{2W}{k}}$

The particle will move between x_m and $-x_m$ and its speed will be a maximum at $x = 0$.

1-6

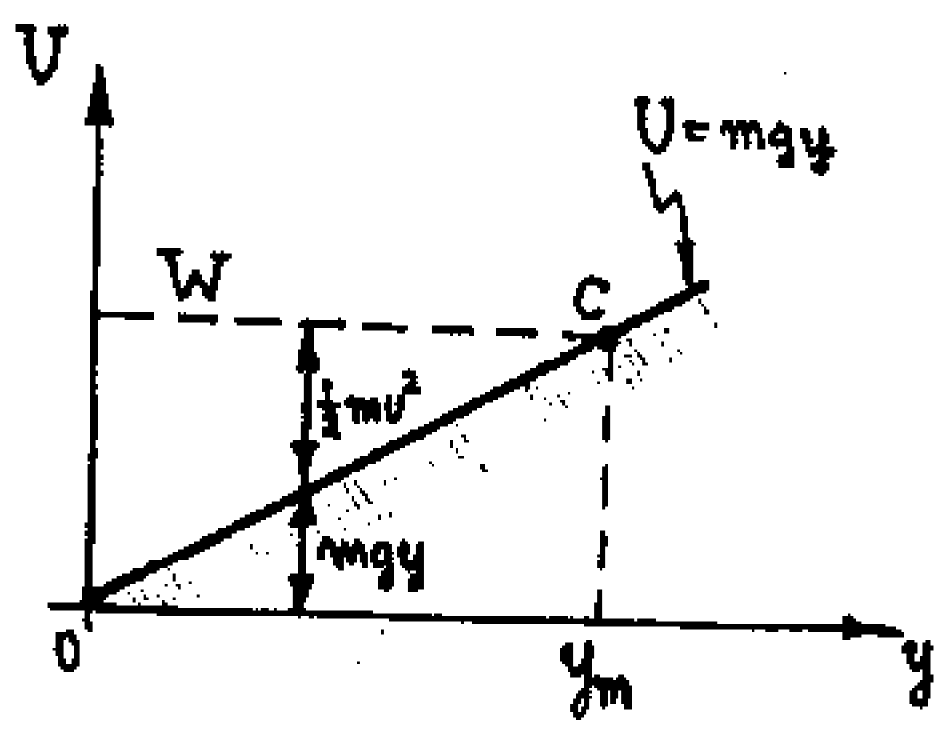

FIG 3

(a) $U = mgy$

The maximum height y_m occurs at the point where $v = 0$. From Eq. (1-5),

$$W = \text{constant} = \frac{1}{2}mv_o^2 = mgy_m$$

or $y_m = v_o^2/2g$

(b) This is clear in Fig. 3; at the point of reversal C where $v=0$, we have a "collision" with the potential barrier.

1-7 By definition, the weight of an atom of a certain element is equal to its atomic weight times the weight of "unit atomic weight", i.e. weight of an atom = AM, and

$$n = \left(\frac{\#\text{atoms}}{AM}\right)\left(\nu\frac{\text{electrons}}{\text{atom}}\right)\left(d\frac{kg}{m^3}\right) = \frac{d\nu}{AM}\ \text{electrons}/m^3$$

Again, by definition, the molecular weight is equal to the weight of one mole of a substance (in grams). Thus, if there are a_m atoms/molecule, we have Molecular weight = $a_m A$ and

$$n = \left(\frac{1}{a_m A}\right)\left(\frac{\text{mole}}{g}\right)\left(10^3\frac{g}{kg}\right)\left(A_o\ \frac{\text{molecules}}{\text{mole}}\right)\left(a_m\frac{\text{atoms}}{\text{molecule}}\right)\left(d\frac{kg}{m^3}\right)\left(\nu\frac{\text{electrons}}{\text{atom}}\right)$$

or $n = \frac{10^3 A_o d\nu}{A}$ electrons/m^3

1-8 The resistance of the wire is

$$R = \rho\ell/A = \frac{3.44\times10^{-8}\times0.5}{\pi\times(1\times10^{-3})^2} = 5.48\times10^{-3}\,\Omega$$

Finally, $V = RI = 5.48\times10^{-3}\times30\times10^{-3} = \underline{1.64\times10^{-4}\,V}$

1-9 The cross section area A of the wire is

$$A = \pi r^2 = 3.14\times(1.03\times10^{-3}/2)^2 = 8.33\times10^{-7}\,m^2$$

(a) $I = JA = 2\times10^6\times8.33\times10^{-7} = \underline{1.666\,A}$

(b) $v = J/nq = \frac{2\times10^6}{8.40\times10^{28}\times1.6\times10^{-19}} = \underline{1.488\times10^{-4}\,m/s}$

(c) ϵ is the voltage per unit length, i.e.

ϵ = Voltage drop in 1m = I x Resistance of 1m $= 1.666\times0.0214 = 0.0357$ V/m, and

$\mu = v/\epsilon = 1.488\times10^{-4}/0.0357 = \underline{4.17\times10^{-3}\,m^2/V\text{-}s}$

(d) Finally, $\sigma = nq\mu = 8.40\times10^{28}\times1.60\times10^{-19}\times4.17\times10^{-3} = \underline{5.61\times10^7(\Omega\text{-}m)^{-1}}$

1-10 (a) The energy of an electron of mass m which is moving with an average drift velocity v is

$$W = \frac{1}{2}mv^2 = \frac{1}{2}m(\mu_n\epsilon)^2$$

If m is in kg, μ in $m^2/V\text{-}s$ and ϵ in V/m, then

$$W = \frac{\frac{1}{2}m\mu_n^2\epsilon^2\ J}{1.6\times10^{-19}\,J/eV} = \frac{m\mu_n^2\epsilon^2}{3.2\times10^{-19}} = 1eV$$

Using μ_n from Table 1-1

$$\epsilon = \left[\frac{3.2\times10^{-19}}{9.11\times10^{-31}\times(1300\times10^{-4})^2}\right]^{1/2} = 4.56\times10^6\,V/m = \underline{45.6\,kV/cm}$$

(b) Since the energy to break a covalent bond in Silicon is 1.1eV (Sec. 1-5) and the required voltage is 45.6kV/cm, we see that it is not practical to generate electron-hole pairs by applying a voltage.

1-11 1.23×10^{23} electrons/cm^3 = $(6.02\times10^{23}$ atoms/mole) x (1 mole/184 g) x (18.8 g/cm^3) x (ν electrons/atom) or

$$\nu = \frac{1.23}{6.02}\times\frac{184}{18.8} = 2$$

1-12 (a) $n = 6.02\times10^{23}\ \frac{\text{atoms}}{\text{mole}}\times\frac{1\ \text{mole}}{63.54g}\times\frac{8.9g}{cm^3}\times\frac{10^6cm^3}{m^3}\times 1\ \frac{\text{electron}}{\text{atom}} = 8.436\times10^{28}$ electrons/m^3

From Eq. (1-15) $\sigma = nq\mu = 8.436\times10^{28}\times1.60\times10^{-19}\times 34.8\times10^{-4} = \underline{4.697\times10^7(\Omega\text{-}cm)^{-1}}$

(b) $v_{drift} = \mu\epsilon = (34.8\times10^{-4})(500) = \underline{1.74\,m/s}$

1-13 $n = 6.02\times10^{23}\ \frac{\text{atoms}}{\text{mole}}\times\frac{1\ \text{mole}}{26.98g}\times\frac{3\ \text{electrons}}{\text{atom}}\times\frac{2.70g}{cm^3}$

$1.81\times10^{23}\ \frac{\text{electrons}}{cm^3}$