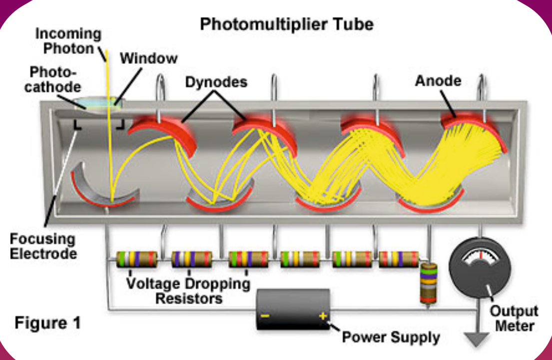
GATE | PSUs

INSTRUMENTATION ENGINEERING

Process Control & Optical Instrumentation

Text Book : Theory with worked out Examples and Practice Questions



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Chapter 1 Process Dynamics

(Solutions for Text Book Practice Questions)

01. Ans: (c)

Sol: For any first order instrument like thermocouple, the time to reach 98% of steady state value is equal to 4 times Time constant.

$$0.98\,T_0 = T_0\,(1 - e^{-t/\tau})$$

$$0.98 = (1 - e^{-t/\tau})$$

$$t = 4\,\tau$$

02. Ans: (c)

Sol: Error is measurement when a ramp of magnitude 'K' is applied is

$$e_{ss} = K\,\tau$$

Where τ = time constant = 100 m sec;

$$e_{ss} = \frac{1^{o}C}{sec} \times 100\times10^{-3}\ sec$$

$$= 0.1^{o}C$$

$\therefore$ The reading of thermocouple will be

$$= 70^{o}C - 0.1^{o}C = 69.9^{o}C$$

03. Ans: (c)

Sol: $96.5 = 100(1 - e^{-t/\tau}) + 30(e^{-t/\tau})$

$96.5 = 100 + e^{-30/\tau}\,(30 - 100)$

$\tau = 10.01$ sec

$98 = 100\,(1 - e^{-t/10}) + 30\,e^{-t/10}$

$e^{-t/10}\,(30 - 100) + 100 = 98$

$t = 35.6$ sec

04. Ans: (a)

Sol: $2\frac{dT_i}{dt} + T_i - T_a = 0$

By applying Laplace Transform on both sides.

$2sT_i\,(s) + T_i\,(s) - T_a(s) = 0.$

$T_i\,(s)\,[2s+1] = T_a(s)$

$$\frac{T_i(s)}{T_a(s)} = \frac{1}{2s+1}$$

$$\frac{T_i(s)}{T_a(s)} = \frac{0.5}{s+0.5}$$

Here cut-off frequency

$$\omega_c = 0.5 = \frac{1}{2}$$

$$\text{or } 2\pi f_c = \frac{1}{2}$$

$$f_c = \frac{1}{4\pi}\ \text{Hz}$$

Chapter 2 Controller Tuning

01. Ans: (b)

Sol: $K_u = 10$

$P_u = 8Hz$

In case of Ziegler Nichols tuning for proportional controller

$K_P = 0.5\,K_u = 0.5\times10 = 5.$

02. Ans: (a)

Sol: Distance between the roll point and the point at which the thickness is measured

$= d = 0.5$ m

v = velocity of the sheet = 0.2 m/s

$$\text{delay} = \frac{d}{v} = \frac{0.5}{0.2} = 2.5 \text{ sec}$$

$\therefore$ T.F $= e^{-2.5\,s}$

03. Ans: (c) & (d)

Sol: OLTF $= K\,e^{-2.5\,s}$

$\angle$OLTF $= -2.5\,\omega$, |OLTF| = K

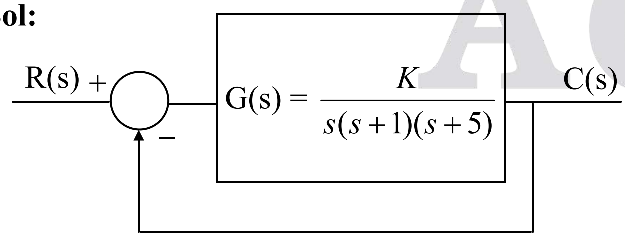
Ultimate value of K for stability = 1

$-2.5\,\omega = -\pi$,

$$\omega = \frac{\pi}{2.5} = 0.4\,\pi \text{ rad/sec}$$

04. Ans: (c)

Sol:



Characteristics equation

$$1 + \frac{k}{s(s+1)(s+5)} = 0$$

$$s^3 + 6s^2 + 5s + K = 0$$

By R-H criteria

s^3	1	5
s^2	6	K
s^1	$\frac{30-k}{6}$	0
s^0	K	

$K_u = 30$

As, $0 < K < 30$ stable

$6s^2 + k = 0$

$6s^2 + 30 = 0$

$s^2 = -30/6 = -5$

$s = \pm\, j\sqrt{5}$

Chapter 3 Control Strategies

01.

Sol: **a)** For, U(s) = 0

By, mason's gain formula

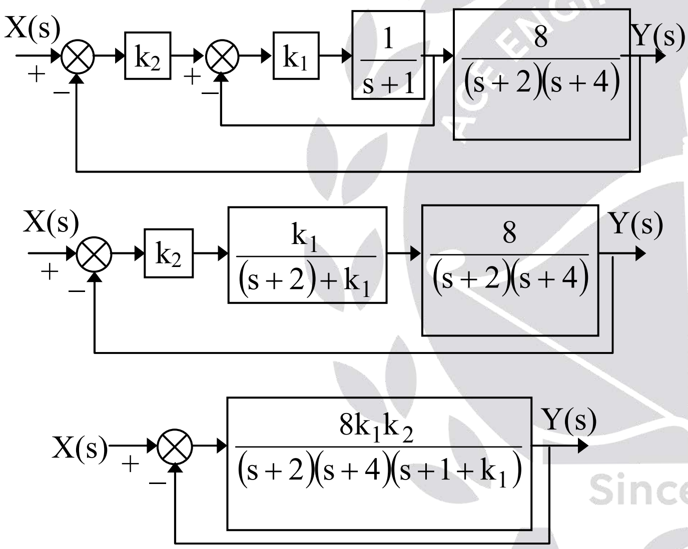
$$\frac{Y(s)}{W} = \frac{G_P(s)\left[1+G_f(s)\,G_C(s)\right]}{1+G_P(s).H(s)\,G_C(s)}$$

b)In order to eliminate the effect of W.

$$G_f(s) = -\frac{1}{G_C(s)}$$

02. Ans: (d)

Sol:



$$\frac{Y(s)}{X(s)} = \frac{8k_1k_2}{(s+2)(s+4)(s+1+k_1)+8k_1k_2}$$

Thus, characteristics equation is

$(s+2)\ (s+4)\ (s+1+k_1) + 8k_1k_2 = 0$

$s^3 + (7+k_1)s^2 + (14+6k_1)s + 8 + 8k_1 + 8k_1k_2 = 0$

According to R-H array

s^3	1	$14+6k_1$
s^2	$7+k_1$	$8(1+k_1+k_1k_2)$
s^1	$\frac{(7+k1)(14+6k1) - 8(1+k_1+k_1k_2)}{7+k_1}$	0
s^0	$8(1+k_1+k_1k_2)$	0

For stable system, all the elements of first column should be greater than zero. By substituting all the given options in coefficient of S^1 will give negative and zero values except option (d).

03.

Sol: Applying Mason's gain formula

$$TF = \frac{Y(S)}{D(S)} = \frac{1+K\cdot\frac{1}{s+2}}{1-\left[50\cdot\frac{1}{s+2}(-1)\right]} = 0$$

$$1+K\cdot\frac{1}{s+2} = 0$$

$s + 2 + K = 0$

$K = -(s+2)$

At frequency ($\omega = 0$)

$K = -2$

Chapter 4 Control Valves

01.

Sol: P = 24 × 0.433

= 10.392 Psi

We know for valve

$$C_V = Q\sqrt{\frac{G}{\Delta P}}$$

Where, Q = flow rate

ΔP = differential pressure across the valve.

G = Specific gravity of water

So,

$$C_V = 120\sqrt{\frac{1}{10.392}}$$

= 37.22

02.

Sol: Maximum out flow = maximum inflow

= 120gpm

ΔP = (26–14) × (0.433)

= 5.196 Psi

$$\text{So, } C_v = Q\sqrt{\left(\frac{G}{\Delta P}\right)}$$

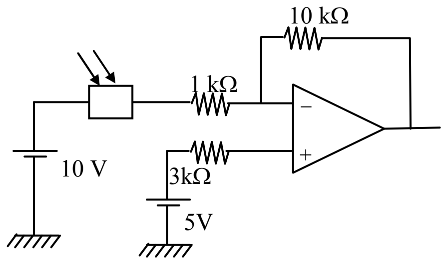
$$= 120\sqrt{\left(\frac{1}{5.19}\right)}$$

= 52.67

Chapter 1 Optical Sources & Detectors

(Solutions for Vol-1_Classroom Practice Questions)

01.
Sol:



1st case:

$R_p \rightarrow 1\ k\Omega$, no 10 V source

2nd case:

$R_p \rightarrow 5\ k\Omega \rightarrow$ 10 V source is present

So, $V = V_{01(\text{Only}10V)} + V_{02(\text{Only}5V)}$

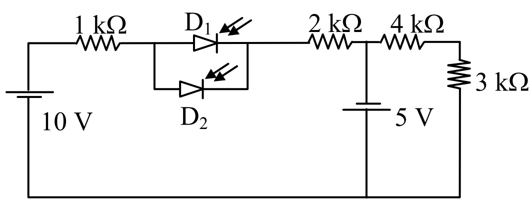
$$V = \frac{-10\,k\Omega}{1k\Omega + R_p}$$

$$= \left(\frac{-10k\Omega}{1k\Omega + 5k\Omega}\right)\times 10 + \left(1 + \frac{10k\Omega}{1k\Omega + 1k\Omega}\right)\times 5$$

$$V = \left(\frac{-10k\Omega}{6k\Omega}\times 10\right) + \left(1 + \frac{10k\Omega}{2k\Omega}\right)\times 5$$

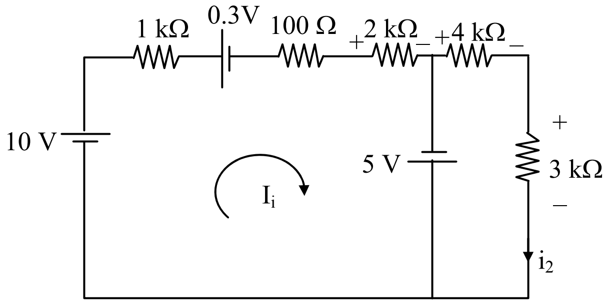
$V = 13.33$ V

02.
Sol:



D_1, D_2 are in forward bias

D_2–ON, D_1 –OFF



$V_{2k} = ?$

$V_{3k\,\Omega} = ?$

$$i_2 = \frac{-5V}{4k\Omega + 3k\Omega} = \frac{-5V}{7k\Omega} = -0.714\ mA$$

$V_{3k\,\Omega} = i_2 \times 3\ k\Omega$

$= (-0.714) \times 3 \times 10^3$

$= -2.14$ V

From circuit

$I_i = 1.41$ mA

So

$V_{2k} = 1.41\ mA \times 2\ k\Omega = 2.8$ V

03. Ans: (c)

Sol: Given data.

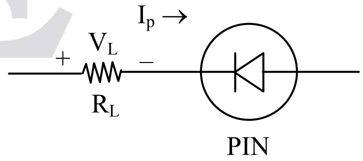
$C_j = 6$ pF

$A = 10\ mm^2$

$R = 0.5$ A/W

$I = 1 mW/cm^2$

$R_L = 100\ k\Omega$



$V_L = ?$

We know

$V_L = I_P \times R_L$

$$R = \frac{I_p}{P_0}$$

$P_0 = A \times I$

$I_p = \frac{0.5A}{W} \times A \times I$

$I_p = \frac{0.5A}{W} \times 10mm^2 \times \frac{1mW}{10mm^2}$

$I_p = \left(0.5 \times \frac{10}{100} \times 1m\right) Amp$

$I_p = 5\times10^{-5}$ amp

$V_L = I_p \times R_L = 5\times10^{-5} \times 100\ k\Omega$

$\therefore\ V_L = 5$ volts

04. Ans: (c)

Sol: Given:

$\eta = 0.65$

$\lambda = 900$ nm

$P_0 = 0.5\ \mu w$

$I_m = 10\ \mu A$

$M = ?$

$M = \frac{I_m}{I_p} = \frac{10\mu A}{I_p}$

We know

$\eta = \frac{EI_p}{P_0 q}$

$0.65 = \frac{hcI_p}{\lambda P_0 q}$

$\Rightarrow 0.65 = \left(\frac{6.6\times10^{-34} \times 3\times10^{8}}{900n \times 0.5\times10^{-6} \times 1.6\times10^{-19}}\right) \times I_p$

$\Rightarrow\ I_p = 2.36 \times10^{-7}$

$M = \frac{10\mu A}{2.36\times10^{-7} A}$

$= 42.4 \approx 43$

05. Ans: –1V

Sol: Output is independent V_r

06. Ans: 2

Sol: Given

Area = 10 mm^2

Sensitivity = 0.5 A/W

Intensity = 4 W/m^2

Photodiode current

I_p = Area × sensitivity × Intensity

$I_P = 10\ mm^2 \times 0.5\ A/W \times 4W/m^2$

$I_p = 20\ \mu A$

I to V converter sensitivity is 100 mV/μA

So, $V_o = \frac{100mV}{\mu A} \times 20\mu A$

$= 2$ Volt

07. Ans: 75.18

Sol: $\frac{I}{P} = \frac{\eta e\lambda}{hc}$

$I = \frac{\eta e \lambda}{hc} \times P$

$= \frac{0.75\times1.6\times10^{-19} \times 830\times10^{-9} \times 100\times10^{-6}}{6.624\times10^{-34} \times 2\times10^{8}}$

$I = 75.18\mu A$

Chapter 2 LED's & LASERs

01. Ans: (b)

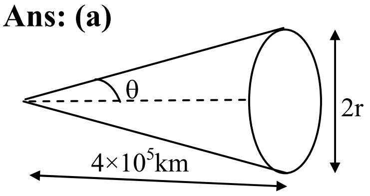
Sol: $2i = 115^0.34' = 115.566^0$,

$i = 57.783^0$, $\quad u = \tan i = \tan 57.783^0$

$= 1.587$

02. Ans: (a)

Sol:



$\theta = 1$ m rad

$$\tan\theta = \frac{r}{4\times10^5\times1000} = 1 \text{ mrad}$$

$(\tan\theta \approx \theta)$

$r = 4\times10^5$ meters

$= 400$ km

Diameter $= 2\times r$

$= 2\times400$ km

$= 800$ km

03. Ans: (b)

Sol: Given:

$L = 500$ mm

Bandwidth $= 1500$ MHz

$\Delta f = ?$

Number of longitudinal oscillating modes

$$= \frac{BW}{\Delta f}$$

We know

$$\Delta f = \frac{C}{2L}$$

Number of longitudinal oscillating modes

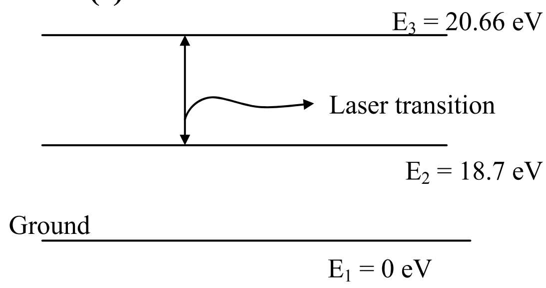
$$= \frac{1500\,\text{MHz}}{\left(\frac{3\times10^8}{2\times500\times10^{-3}}\right)}$$

$$= \frac{1500\times10^6}{3\times10^8}\times1000\times10^{-3}$$

$= 5$

04. Ans: (c)

Sol:



05. Ans: (c)

Sol: $E_3 - E_2 = \dfrac{hc}{\lambda}$

$$\lambda = \frac{hc}{E_3 - E_2} = \frac{6.625\times10^{-34}\times3\times10^8}{(20.66-18.7)\times1.6\times10^{-19}\,\text{J}}$$

$= 633.8$ nm

06. Ans: (d)

Sol: Given

$\lambda = 6328\,\overset{0}{\text{A}}$

Bandwidth $= 1$ MHz

$C_l = ?$

We know

$$C = \frac{C_\ell}{C_t}$$

$$C_l = 3\times10^8\times\frac{1}{1\text{MHz}} \quad (\because C_t = \frac{1}{f})$$

$C_l = 300$ m

07. Ans: 40

Sol: Area for photodiode D_1

$A_1 = 10\text{mm}\times(5\text{mm} + 0.1\text{mm})$

$= 51\times10^{-6}\ \text{m}^2$

Area for photodiode D_2

$A_2 = 10\text{mm}\times(5\text{mm} - 0.1\text{mm})$

$= 49\times10^{-6}\ \text{m}^2$

$$P_1 = 50\left(\frac{W}{m^2}\right)\times51\times10^{-6}(m^2)$$

$P_1 = 50 \times 51 \times 10^{-6}(W)$

$P_2 = 50\left(\frac{W}{m^2}\right) \times 49 \times 10^{-6}(m^2)$

$P_2 = 50 \times 49 \times 10^{-6}(W)$

Difference between photo currents

$\Delta I = I_{D1} - I_{D2}$

= Photodiode sensitivity × ΔP

$= 0.4\left(\frac{A}{W}\right) \times (P_1 - P_2)$

$= 0.4 \times 50(51-49) \times 10^{-6}$

$= 0.4 \times 50 \times 2 \times 10^{-6}$

= 40 (μA)

08. Ans: 2

Sol: $E_g = \frac{hC}{\lambda}$

$$E_g = \frac{4.13567 \times 10^{-15} \times 3 \times 10^8}{620 \times 10^{-9}}$$

= 2eV

Chapter 3 Interferometers

01.

Sol: Given data:

$t = 5\ \mu m$

$n = 5$

$\lambda = 589$ nm

$\mu_g = ?$

We know

$t(\mu_g - 1) = n\lambda$

$\Rightarrow 5\times10^{-6}(\mu_g - 1) = 5\times589\times10^{-9}$

$\Rightarrow (\mu_g - 1) = \dfrac{5\times589\times10^{-9}}{5\times10^{-6}}$

$\Rightarrow (\mu_g - 1) = 0.589$

$\Rightarrow \mu_g = 1.589$

02.

Sol: Given data:

$\lambda = 515$ nm

Refractive index $(\mu) = 1.6$

$\theta_R = 45^o$

$t = ?$

we know

$t(\mu - 1) = n\lambda$

$$t = \frac{n\lambda}{(\mu-1)}$$

$\Rightarrow \quad t = \dfrac{515\times10^{-9}}{1.6-1} = 8.58\times10^{-7}$

$\Rightarrow \quad t = 0.85\ \mu m$

03.

Sol: Given data

$t = 1.5\ \mu m$

$\lambda = 0.5\ \mu m$

$n = ?$

We know

$t = \dfrac{n\lambda}{2}$

$\Rightarrow 1.5\times10^{-6} = \dfrac{n\times0.5\times10^{-6}}{2}$

$\Rightarrow \dfrac{1.5\times10^{-6}\times2}{0.5\times10^{-6}} = n$

$\Rightarrow n = 6$

04.

Sol: Given data:

$n = 100$

$\lambda = 6328 A^o$

$t = 20$ cm

$\mu = ?$

We know

$$2t(\mu - 1) = n\lambda$$

$\Rightarrow 2\times20\times10^{-2}(\mu - 1) = 100\times6328\times10^{-10}$

$\mu = 1.0001582 \approx 1$

05.

Sol: Given data

$R.I = \mu_g = 1.53$

$\mu_{air} = 1.0$

$$R = \left(\frac{\mu_g - \mu_{air}}{\mu_g + \mu_{air}}\right)^2$$

$R = 0.044$

$R = 4.4$ % of loss

Chapter 4 Fiber Optics

01. Ans: (d)

Sol: $NA = \sqrt{n_1^2 - n_2^2}$

$= \sqrt{(1.44)^2 - (1.4)^2}$

$= 0.34$

02. Ans: (c)

Sol: Given data

$\varepsilon_r = 2.5$

n = ?

n = refractive index

We know,

$n = \sqrt{\varepsilon_r \mu_r}$

ε_r = relative permittivity

μ_r = relative permeability

$n = \sqrt{2.5}$ ($\because \mu_r = 1$)

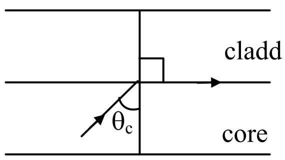
$= 1.58$

03. Ans: (d)

Sol: $n_1 = 1.6$

$n_2 = 1.422$

$\theta_c = ?$



$$\frac{\sin\theta_c}{\sin 90^o} = \frac{n_2}{n_1}$$

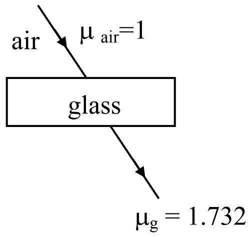
$$\theta_c = \sin^{-1}\left(\frac{1.422}{1.64}\right)$$

$= 60.12^0$

$\simeq 60^0$

04. Ans: (c)

Sol: $\mu_g = 1.732$



$$\tan\theta_B = \frac{\mu_g}{\mu_{air} = 1}$$

$\theta_B = \tan^{-1}(1.732)$

$\theta_B = 60^o$

05. Ans: (a)

Sol: Given $\mu_{glass} = 1.720$

$$R = \left(\frac{\mu_{air} - \mu_{glass}}{\mu_{air} + \mu_{glass}}\right)^2 \times 100$$

$$R = \left(\frac{1-1.72}{1+1.72}\right)^2 \times 100$$

$= 7\ \%$

06. Ans: (d)

Sol: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Given

$n_1 = 1.641$

$n_2 = 1.422$

$$\theta_c = \sin^{-1}\left(\frac{1.422}{1.641}\right)$$

$= 60^o$

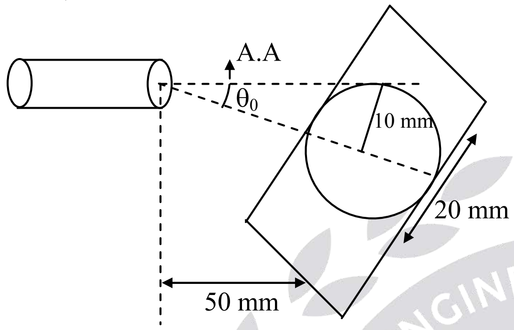
07. Ans: (d)

Sol: $\frac{\mu_t}{\mu_g} = \frac{1.33}{1.5} = \frac{C}{V_t} \times \frac{V_g}{C}$

$\frac{V_t}{V_g} = \frac{1.55}{1.33}$

08. Ans: (b)

Sol: NA = ?



$NA = \sqrt{n_1^2 - n_2^2}$

$NA = \mu_0 \sin\theta_0$

$NA = \sin\theta_0$

$NA = \frac{10}{\sqrt{10^2 + 50^2}}$

$= 0.196$

≈ 0.2

09. Ans: 0.75

Sol: $\frac{n_1}{n_2} = \frac{t_1}{t_2} = 0.75 \quad (n \propto t)$