QUESTIONS FOR QUALIFYING EXAM

CIRCUIT & ELECTRONICS

1. Describe the operation of an OPAMP amplifier. Explain the summing point constraint and its origin

2. Describe the limitations of an OPAMP circuit operating at high frequency. Explain the difference between gain-bandwidth product and slew rate limits

3. Describe the operation of a Schmitt trigger

4. Analyze the operation of a lowpass RC circuit in the time domain

5. Analyze the operation of a lowpass RC circuit in the frequency domain

6. Describe the operation of a half-wave rectifier with smoothing output capacitor

7. Discuss stable biasing of a common emitter amplifier

8. Describe the small-signal operation of a common emitter amplifier

9. Discuss the high-frequency response of a common-emitter amplifier and define the upper cutoff frequency

10. Draw and discuss the input and output characteristics of a bipolar junction transistor (BJT)

11. Discuss equivalent models for a bipolar junction transistor operating in cutoff, in the active region and in saturation

12. Write equations describing the operation of an n-channel MOSFET in the triode region and in the saturation region. Discuss the boundary between the two operating regions

13. Describe the operation of an OPAMP integrator

14. Describe the operation of an emitter follower amplifier

15. Describe the operation of a noninverting OPAMP amplifier as a feedback system

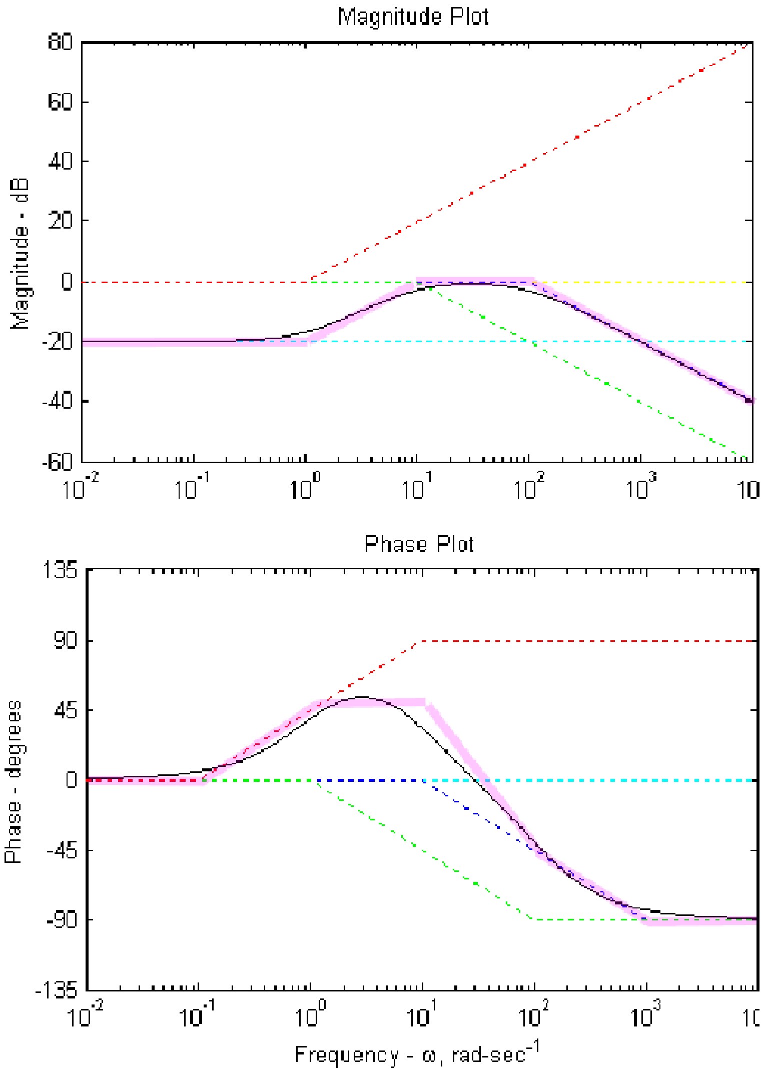
16. Discuss the basic operation of a digital oscilloscope. Define sampling rate and analog bandwidth

17. Derive the transfer function of a series L-C-R circuit, define the Q-factor of the circuit and draw a Bode plot for the circuit input-output transfer function

SIGNALS & SYSTEM AND CONTROLS

1. Describe the mathematical definition of linearity and time invariance.
2. Describe the input and output relation of linear time invariant systems in time domain and frequency domain.
3. Explain differences between Laplace transform and Fourier transform in frequency domain.
4. Explain sampling and reconstruction theorem.
5. Explain how Fourier transform and Fourier series expansion are related.
6. Explain Parseval's relation for a periodic signal and its meaning.
7. Consider Fourier transform of a rectangular pulse in time domain. Please explain scale property of Fourier transform.
8. Consider Fourier transform of a sinc function in time domain. Please explain duality of Fourier transform.
9. Explain modulation property of Fourier transform. Please describe applications of modulation properties in communication systems.
10. Explain how we can determine stability of a linear time invariant systems in (1) continuous time domain and (2) discrete time domain.
11. Explain region of convergence (ROC) of z-transform in terms of causal and anti-causal signals.
12. Discuss advantages and disadvantages between Finite Impulse Response (FIR) filter and Infinite Impulse Response (IIR) filter.
13. Describe auto-correlation and cross-correlation in (1) time domain and (2) frequency domain.
14. Explain how one can implement a correlation operation by use of convolution operator.
15. Discuss advantages and disadvantages between feed-forward control system and feedback control system.
16. State the definition of gain margin and phase margin. Draw a generic Bode phase/magnitude plot and show the gain and phase margin. How are these related to stability of a feedback system?

17. Below is the magnitude and phase bode plot of a transfer function. Note that both the actual curve (solid line), the asymptotes (dotted lines), and their sum (wide line) are shown. Find the transfer function that corresponds to this Bode plot.

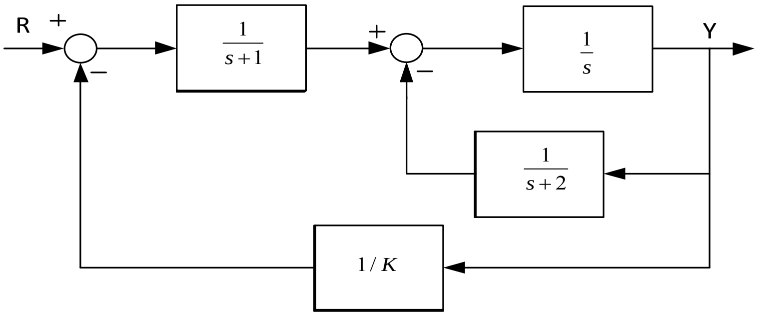


18. A system has the following characteristic equation

$$s^3 + 8s^2 + 14s + 24$$

Use the Routh Stability Criterion and the Hurwitz Stability Criterion to determine if this system is stable.

19. Consider the following block diagram



Reduce the block diagram to unity feedback form and find the system characteristic equation.

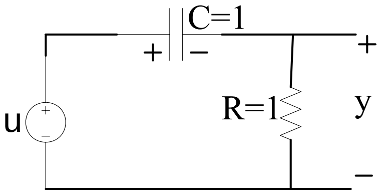
20. An open loop transfer function is given by

$$GH(s) = \frac{1}{s}$$

Sketch the Nyquist stability plot for this type 1 system.

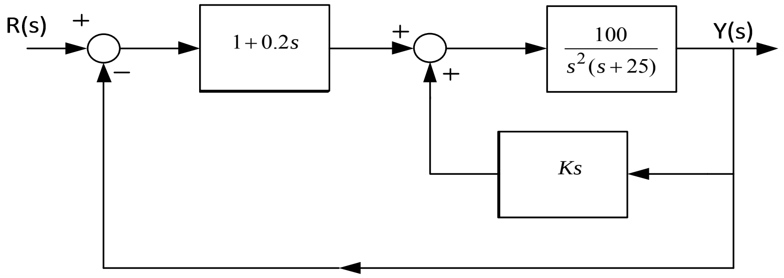
21. An RC network is shown below where

$u = 2e^{-t}$ and the initial voltage across the capacitor is 1 volt.



Write the differential equation for the circuit and show how the LaPlace transform of y(t) is obtained. Finally, use the final value theorem to find the steady-state value of the circuit. Does the theorem give you the answer that you expected? why?

22. For the block diagram below determine the steady state error to a step response. Also, for what range of K is your answer valid, if any.



23. Consider a multivariable system described by the differential equations

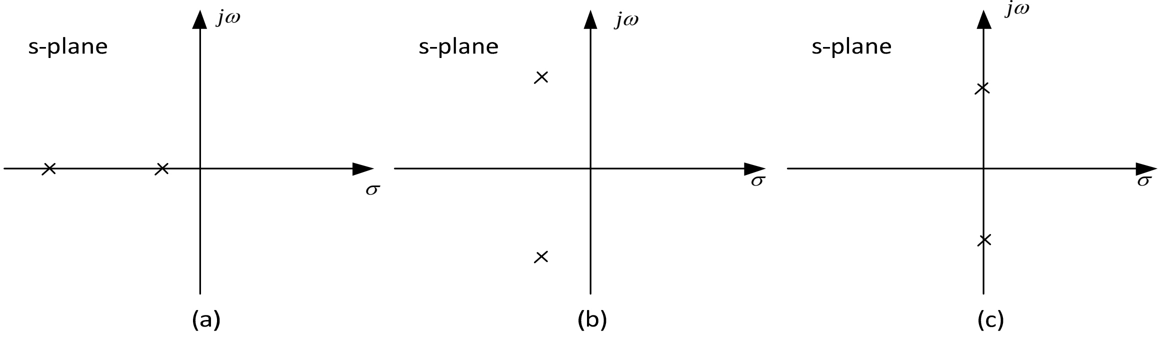
$$\frac{d^2c_1}{dt^2}+4\frac{dc_1}{dt}-3c_2=r_1+2w$$
$$\frac{dc_2}{dt}+\frac{dc_1}{dt}+c_1+2c_2=r_2$$

If the state variables of the system are assigned as

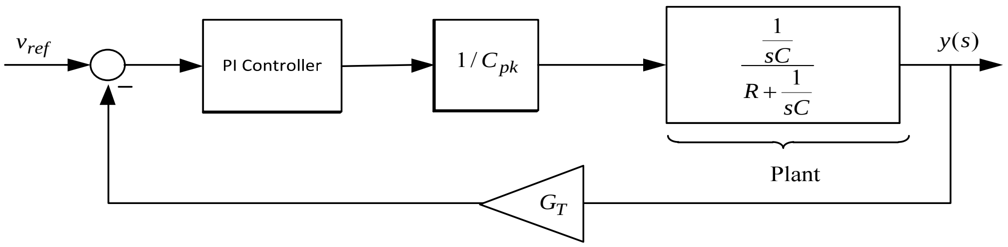
$$x_1=c_1$$
$$x_2=\frac{dc_1}{dt}$$
$$x_3=c_2$$

Determine the state equation and output equation in matrix form.

24. For the following figures discuss the damping and sketch a time domain step response for each.

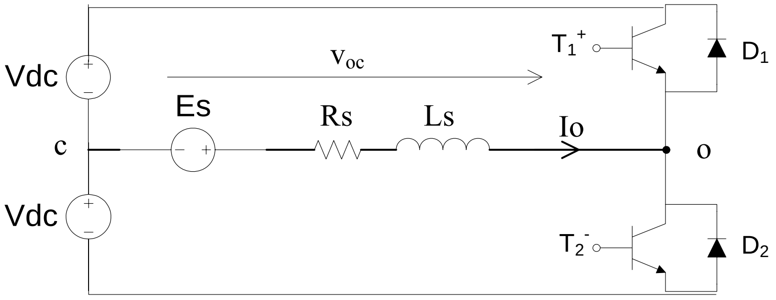


25. Given the control system diagram below answer the following questions:



a. Write the expression for the open loop transfer function, $G_{OL}(s)$
b. Derive the expression for the phase of the plant transfer function, Gp(s)
c. Assuming that at the crossover frequency, fc, the integral part of the controller can be neglected find the expression for calculating the proportional gain, Kp.

26. Below is the circuit of a half-bridge converter.



Assume that the transistor and diodes act as ideal switches with null transition times.

Derive the state space model of the converter given that the current Io is selected as the state variable and the input vector is

$$u = \begin{bmatrix} Voc \\ Es \end{bmatrix}$$

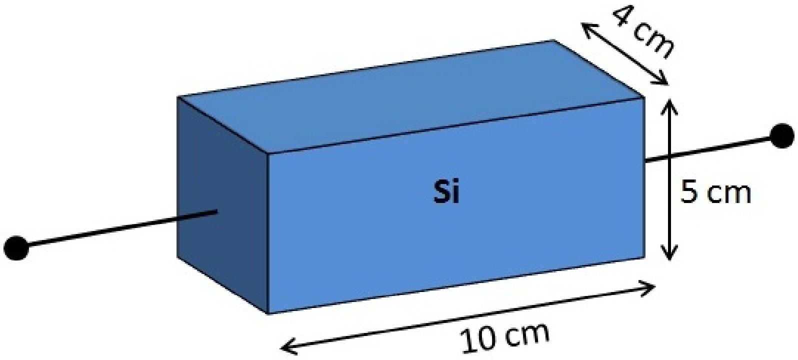
Using this result find the transfer function between duty-cycle, *d*(t), and load current. To do this assume that an average voltage is generated equal to

$$\bar{V}_{oc} = \frac{1}{T_s}(T_s V_{DC} d(t) - V_{DC}(1-d(t))T_s)$$

where duty cycle is the ratio between the time duration of the $+V_{DC}$ voltage application period and the duration of the whole modulation period Ts.

SEMICONDUCTOR DEVICES

Boltzmann's constant	K = 1.38e-23 J/K = 8.62e-5 eV/K;
Electric charge magnitude	q = 1.6e-19 C;
Permittivity of free space	ε_o = 8.85e-14 F/cm;
Planck's constant	h = 6.63e-34 J.s = 4.14e-15 eV.s;
Speed of light	c = 2.998e10 cm/s;



1. Consider the above shown Si sample (n_i = 1e10 cm^{-3}) doped with a donor concentration of 5e+18 cm^{-3} and an acceptor concentration of 5e16 cm^{-3}. The electron mobility is 1000 $cm^2/(V*s)$ and the hole mobility is 600 $cm^2/(V*s)$.

   a. Is the sample n-type or p-type?

   b. Calculate the free electron and hole concentrations at room temperature.

   c. Determine the resistivity of the sample (consider both electron and hole mobilities).

   d. Calculate the current through the sample, given an applied voltage of 50V across the terminals shown.

2. Consider a p-type Si sample with doping concentration $N_A = 10^{18}$ cm^{-3}. (a) Where is the Fermi level (E_F) relative to intrinsic level (E_i) at 300K? kT = 0.026 eV at 300K, $n_i = 10^{10}$ cm^{-3}. (b) Determine the energy difference $E_F - E_V$. Given that $N_V = 1.08 \times 10^{19}$ cm^{-3} (c) Draw a band diagram showing the above energy levels.

   [Hints: $E_F - E_V = kT \ln(N_V / p_0)$]

3. A semiconductor, in thermal equilibrium, has a hole concentration of $p_0 = 2\text{x}10^{16}$ cm^{-3}. The minority carrier life time = $3\text{x}10^{-7}$ s. (Assume, $n_i = 10^{10}$ cm^{-3}) (a) Determine the thermal equilibrium recombination rate of electrons. (b) Determine the recombination rate of electrons if an excess electron concentration of $\Delta n = 10^{13}$ cm^{-3} exists. (c) Calculate the change in the recombination rate when excess electron concentration exists (compared to thermal equilibrium).

[Hints: $R_n = \dfrac{\Delta n}{\tau_{n_0}}$]

4. Consider an n-type Si sample with doping concentration $N_d = 2\text{x}10^{17}$ cm^{-3}. ($E_g = 1.1$ eV, kT = 0.026 eV and $n_i = 1.3\text{x}10^{10}$ cm^{-3} at 300K). (a) Where is the Fermi level (E_F) relative to intrinsic level (E_i) at 300K? (b) Calculate the Fermi level position relative to conduction band (E_C-E_F) and relative to valence band (E_F-E_V). (c) Draw a band diagram showing all of the energy level positions calculated.

5. Consider a Si p+-n junction (n_i = 1e10 cm^{-3} at 300K) with a donor concentration of 1.2e16 cm^{-3} in the n-type region at T = 212 K. The critical field of the avalanche breakdown is 300 kV/cm. The relative dielectric permittivity of Si is 11.7.What is the breakdown voltage of the diode?

6. Consider a Si p-n junction with doping of 2e16 cm^{-3} in both the p-type region and n-type regions at room temperature (T = 300 K). The intrinsic carrier concentration is n_i=1e10 cm^{-3}. The diode cross sectional area is 9.6 e^{-2} cm^2. The relative dielectric permittivity of Si is 11.7.

   (a) Find the depletion capacitance at zero bias.

   (b) Find the depletion capacitance at a reverse bias of -1.5V.

   (c) What is the capacitance ratio C_{max}/C_{min} when the bias is changed from 0 to -1.5V.

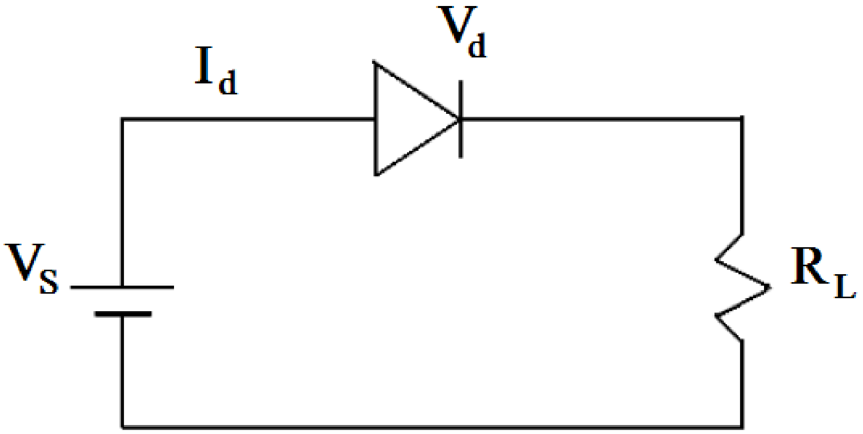
7. Consider a GaAs p-n junction (n_i = 1.8e6 cm^{-3} at 300K). Dopant levels in n and p sides are N_D = 2e17 cm^{-3}, N_A = 1.5e15 cm^{-3}. Diffusion length of electrons and holes are L_n = 105 µm, L_p = 40 µm. Calculate the injected electron concentration at the point on the p-side, 1 µm away from edge of depletion region, when the p-n junction is forward biased at 0.32 V.

8. Consider a Si p-n junction (n_i = 1e10 cm^{-3} at 300K) with the following parameters: N_a = 3.8e14 cm^{-3} on the p-side, N_d = 2e16 cm^{-3} on the n-side. A forward bias V_f = 0.4V is applied to the p-n junction. Electron mobility μ_n = 1000 $cm^2/(V*s)$ and the electron life time τ_n = 50 ns.

   (a) Find the electron diffusion length L_n in cm. [Hint: Diffusion Coefficient D = $\mu*kT/q$]

   (b) Find the excessive injected electron concentration on the p-side, at the edge of the depletion region.

9. In the circuit shown above, the battery voltage is 4.4 V. The saturation current parameter I_s of the diode is 0.3 pA. The resistance of the resistor R = 167 Ohms. Find the voltage across the resistor. Use the load-line technique to solve the problem.



10. Consider a contact between a metal having Φ_m = 4.65 eV and an n-type silicon (Φ_s = 4.22eV, χ_s = 3.5eV). N_D = 2.5e16 cm^{-3} at T = 300K.

    (a) Identify the type of contact (Schottky or Ohmic).

    (b) Find the maximum electric field at a reverse bias of -1.4V.

    (c) Does the device conduct due to the majority or the minority carriers?

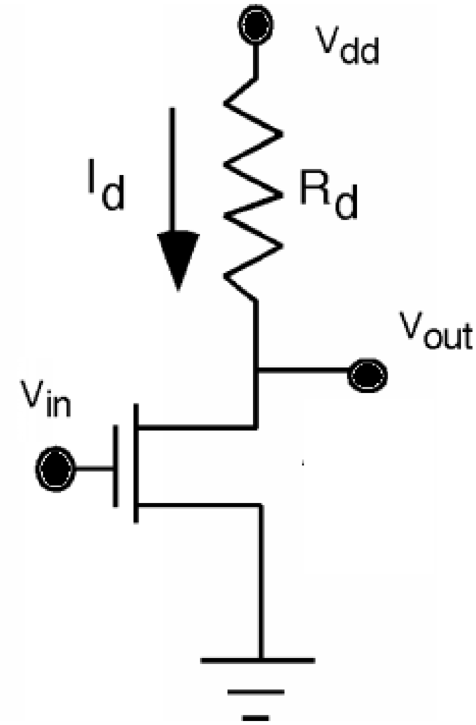
    (d) What are the potential advantages of this type of rectifying structure versus the more conventional p-n type rectifying structures?

11. Consider a Si pnp BJT with the following parameters: $N_{Ae} = 1.4e19$ cm^{-3}, $N_{Db} = 5.5e17$ cm^{-3}, $\mu_n = 1000$ cm^2/Vs, $\mu_p = 400$ cm^2/Vs, W = 0.17 µm, $L_n = 12$ µm, $L_p = 9$ µm. [Hint: $D = \mu*(kT/q)$]

    (a) Estimate the current gain limited by injection efficiency β_o.

    (b) Estimate the common-emitter current gain limited by the recombination in the base β_R.

    (c) Estimate the overall current gain β.



12. The above shown inverter circuit consists of a MOSFET and a load resistor, $R_d = 2.2$ kΩ. The inverter bias voltage is $V_{dd} = 5$ V, the MOSFET threshold voltage V_T is 0.5 V, and the gate input voltage V_{in} is 5 V. Under these conditions, the MOSFET drain voltage is $V_d = 0.5$ V. Assuming that the MOSFET I-Vs are linear at this drain voltage, find the power dissipated in the inverter circuit.

13. Consider a MOSFET with the oxide thickness of 6 nm. The oxide layer dielectric constant d_{ox} is 3.9. The gate length is L= 1.5 µm; the gate width is W= 11 µm. The electron mobility in the channel is 220 cm^2/Vs. The MOSFET threshold voltage is 0.6 V. The gate bias is VGS = 1.8 V. Ignore the velocity saturation effects in the MOSFET.

    (a) At what drain-source voltage does the drain current saturate?

    (b) Find the MOSFET saturation current, I_{sat}.

14. MOSFET has the gate length L = 1 µm, the width W = 12 µm, the oxide thickness 5 nm and the relative dielectric permittivity 3.9. The electron mobility is 310 cm^2/Vs, the gate-threshold voltage offset V_{GT} = 3.5 V and the characteristic velocity saturation field F_s = 1.8e4 V/cm.

    (a) Find the MOSFET saturation current, I_{sat} accounting for the velocity saturation.

    (b) For the drain voltage corresponding to the onset of saturation, find the channel sheet carrier density n_s at the drain end of the channel. [Hint: $I_{sat} = q*W*n_s*v_s$]

15. Consider a Si MOSFET in saturation. The gate length L = 0.5 µm, W = 16 µm, and oxide thickness of 8 nm. The dielectric constants of the oxide and Si are 3.9 and 11.7 respectively. Assume the fringing capacitance factor, $\beta_c = 0.5$. [Hint: Use the Meyer's model]

    (a) What is the gate-source capacitance C_{GS_SAT}?

    (b) What is the gate-drain capacitance C_{GD_SAT}?

ELECTROMAGNETICS

1. Define and discuss electrostatic potential and energy.
2. Explain the boundary conditions of electric and magnetic fields.
3. Discuss magnetic materials and hysteresis.
4. What is Faraday’s law of electromagnetic induction?
5. Write down the four Maxwell’s equations and know their significance.
6. Define scattering parameters.
7. What are propagation constant, characteristic impedance, reflection coefficient, VSWR, phase velocity, group velocity and dispersion?
8. Define skin depth in a conductor.
9. Derive the Helmholtz wave equation in free-space.
10. Discuss the differences between TEM, TE, and TM waves and the media required to allow their propagation.
11. What does wave polarization mean?
12. For a given flux density vector what is the total flux passing through a closed or open surface?
13. Discuss the fundamentals of the Smith chart; load impedance, reflection coefficient, short circuit, open circuit, admittance, and rotation on the chart.
14. What are the differences between a conductor, insulator, and a semiconductor from EM point of view? What is the equation of continuity?
15. Discuss EM wave reflection, refraction, and transmission for different material media.
16. Discuss inductances and capacitances and how to calculate them from fields, what is dielectric polarization?
17. Explain “resonance” from an EM perspective with a practical example.
18. Derive Poisson’s and Laplace’s equations.