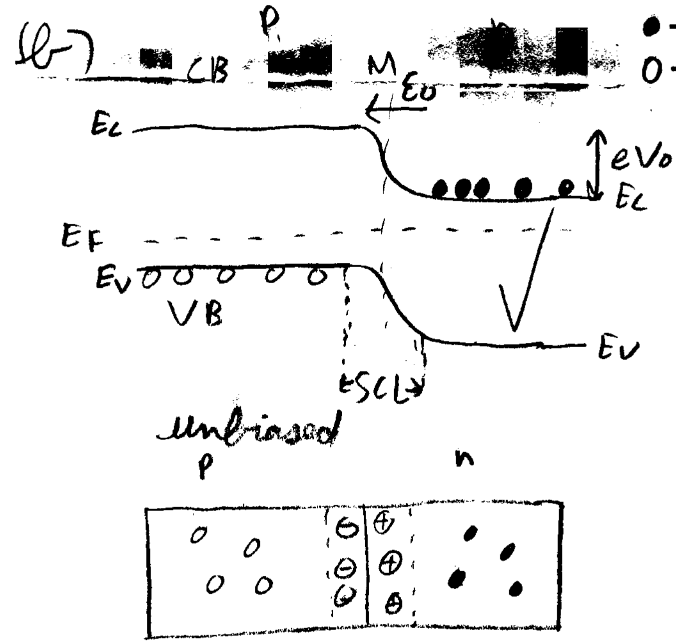
1. Answer any **two** questions from **a** to **c**

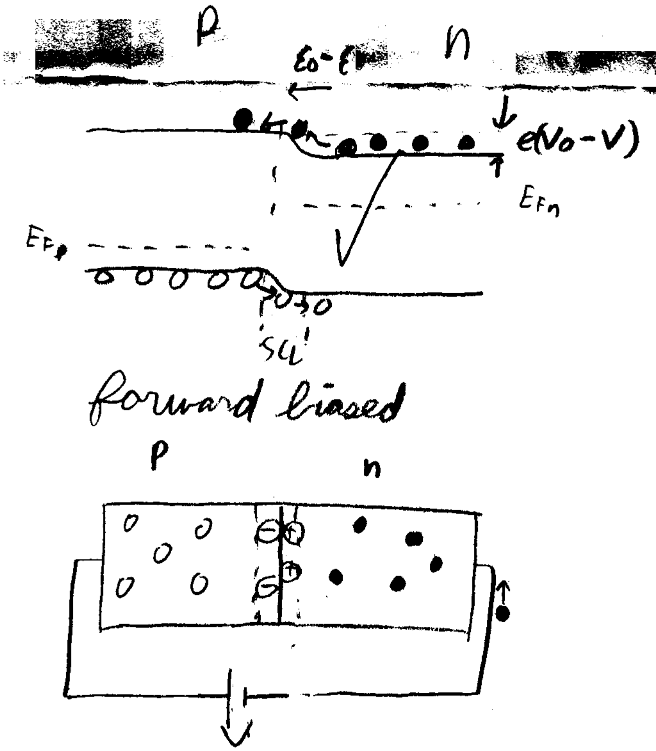
[12.5] **a** Sketch schematically the *E-k* diagrams of direct and indirect bandgap semiconductor, giving an example in each case. What is the significance of these *E-k* diagrams?

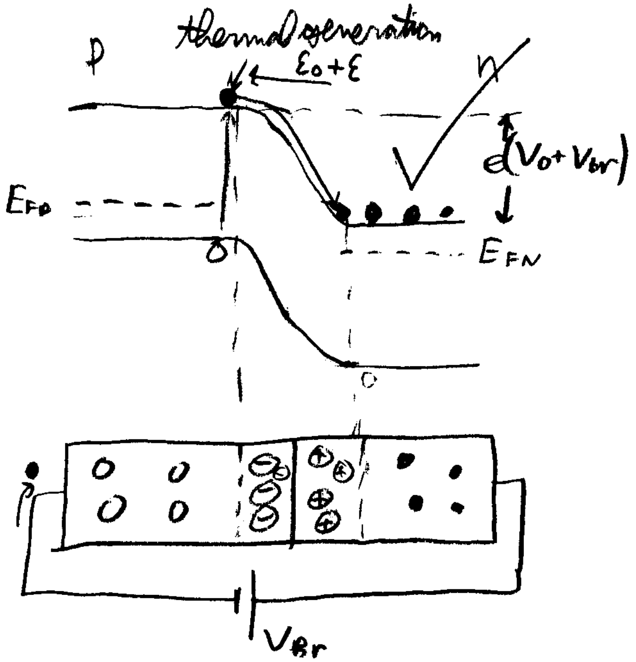
[12.5] **b** Sketch schematically the energy band diagram of unbiased, forward biased and reverse biased *pn* junctions.

[12.5] **c** Sketch schematically the energy band diagram of an unbiased, forward biased and reverse biased Schottky junction a. Sketch its *I-V* characteristics.

(b)







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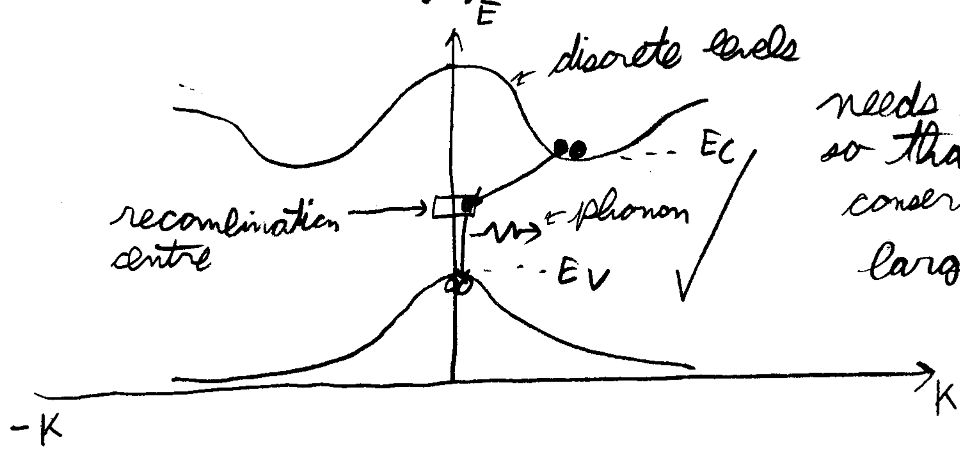
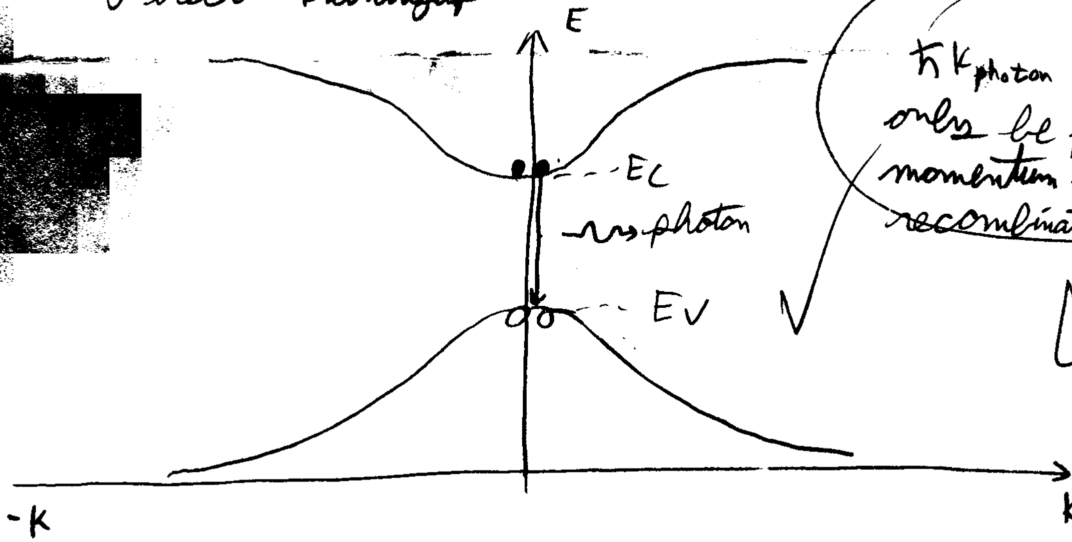
(a) Indirect Bandgap → Si



needs recombination centre so that momentum may be conserved. Phonons can have larger momentum than photons.

Direct Bandgap → GaAs



$\hbar k_{photon}$ is very small, so will only be produced where the momentum change of the electron's recombination is negligible.

These diagrams show why some semiconductors are direct, and others indirect, which determines whether they will readily emit light or not respectively. They are used to show the effects of conservation of momentum on semiconductors.

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[10] **2.** **a** Consider an *npn* bipolar junction transistor which is connected in the common base configuration and operating in the active mode under normal conditions.

(i) Sketch schematically the "transistor diagram", by using rectangular blocks for the emitter, base and collector regions, showing the doping in each case, identifying the depletion regions, and showing the battery connections and the currents in the circuit. In this diagram sketch schematically the minority carrier concentration profile across the base when $V_{EB} = -0.6$ V and $V_{CB} = 12$ V. How does the collector current depend on the emitter current and V_{EB}? What constitutes the transistor action?

(ii) Show in sketch **a** **(i)** how the minority carrier profile changes as V_{EB} is modulated around a dc value.

(iii) Show in sketch **a** **(i)** how the minority carrier profile changes as V_{CB} is changed (for example from 12 V to 13 V). What is the effect on the collector current?

[15] **b** **(i)** Draw the high frequency small signal equivalent circuit of a common emitter (CE) bipolar junction transistor biased to be operating in the normal conditions in the active mode. Explain very briefly the origin of each component in this circuit.

(ii) Derive the small signal current gain β and voltage gain A_V as a function of frequency f when a small signal source with an output resistance R_s is connected to this CE amplifier. (Remember that you had assumed normal operating conditions and active mode). Sketch β and A_V vs. frequency.

3. Consider a *p*-channel *enhancement* MOSFET. The threshold voltage, V_{th}, is −6V.

[4] **a** Sketch schematically the cross section of the device when $V_{GS} = 0$ and $V_{DS} = 0$. Label this diagram clearly and identify all regions (e.g. n^+, n, p^+, p). In the following diagrams you only have to label important parameters and changes. These are schematic sketches. Why are *p*-channel MOSFETs less preferred than *n*-channel MOSFETs?

[4] **b** Consider $V_{GS} = -3$. Sketch the device cross section when $V_{DS} = -1$ and -12 V.

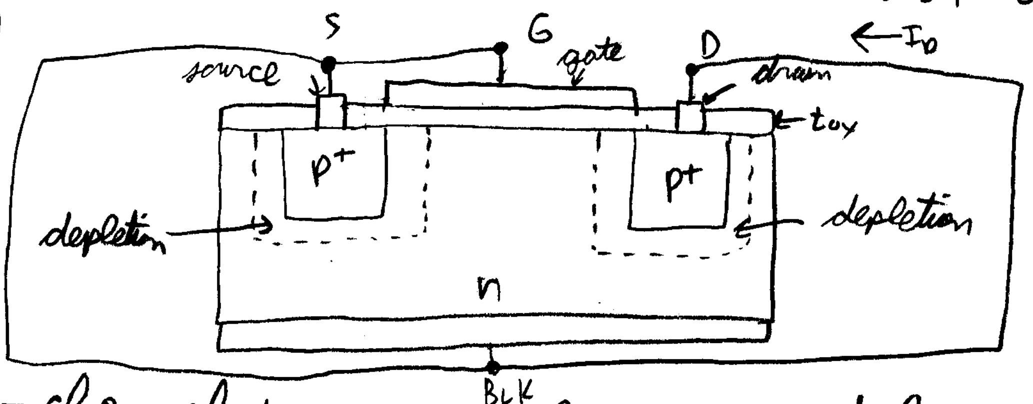
[6] **c** Consider $V_{GS} = -8$V.

- **(i)** Sketch the device cross section when $V_{DS} = -1$.
- **(ii)** Sketch the device cross section when $V_{DS} = -2$.
- **(iii)** Sketch the device cross section when $V_{DS} = -12$.

[7] **d** Sketch schematically I_D vs. V_{DS} for $V_{GS} = 0$, −4V, −6V, −8V and −10V, and identify the above points **c** **(i)**, **(ii)** and **(iii)** on the sketch. Identify the $V_{DS(sat)}$ points and show the locations of I_{DS} and $V_{DS(sat)}$ in this sketch. What is the condition that determines the locations (locus) of I_{DS}, $V_{DS(sat)}$, V_{GS} points in these I_D and V_{DS} characteristics?

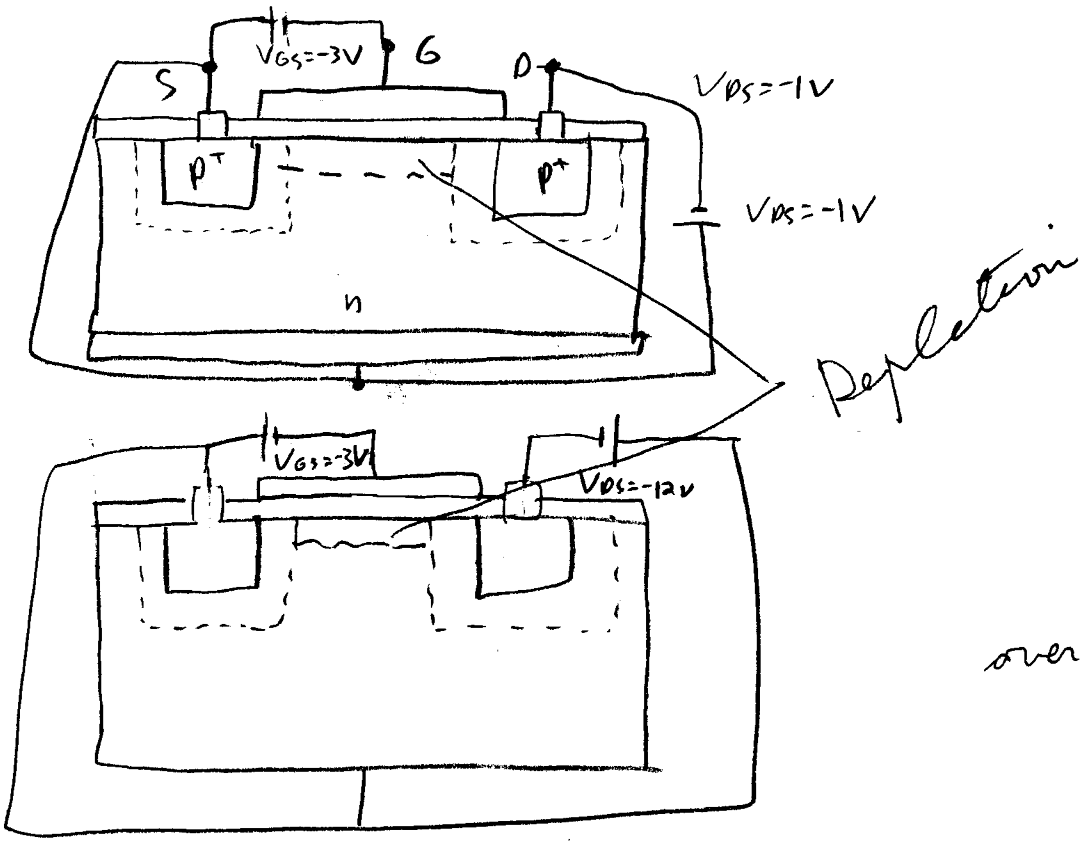
[4] **e** Sketch schematically I_{DS} vs. V_{GS} for $V_{DS} = -20$V. Label your sketch.

(a) $V_{th} = -6V$



p-channel MOSFETs are less preferred because holes have a lower drift mobility than electrons, and hence the device has a higher on resistance.

(b)



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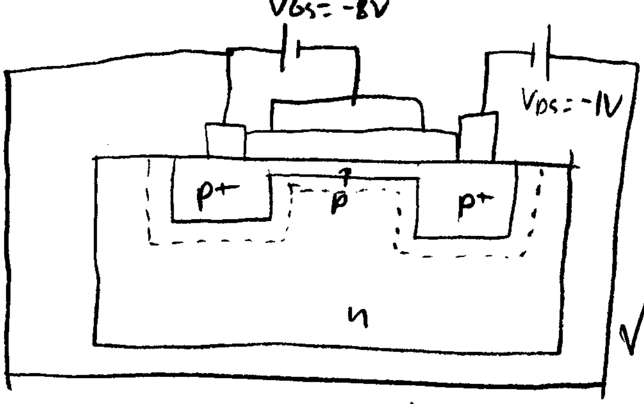
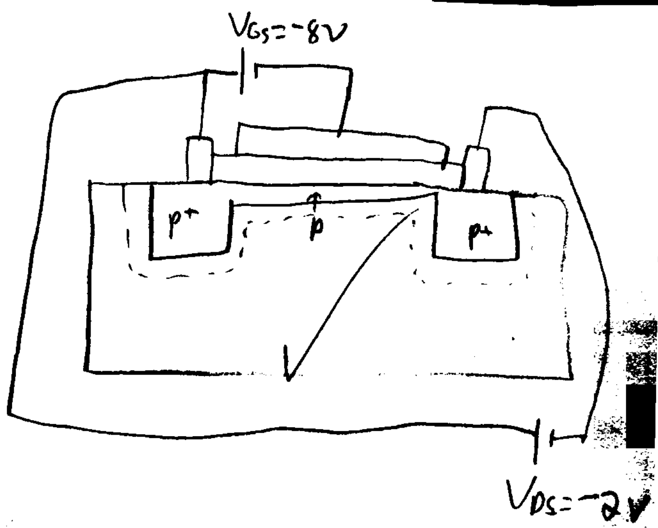
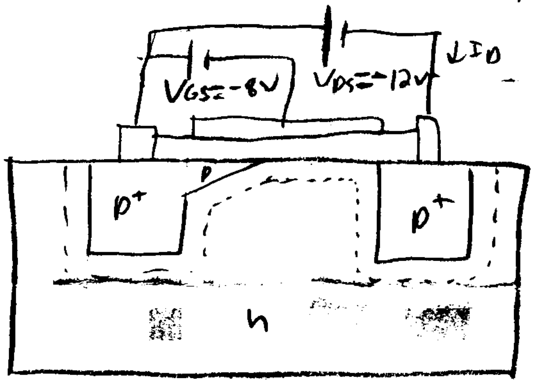
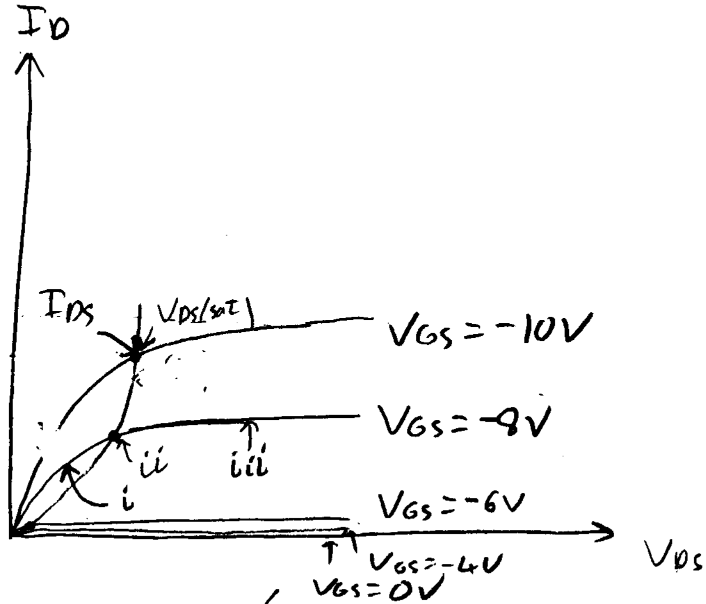






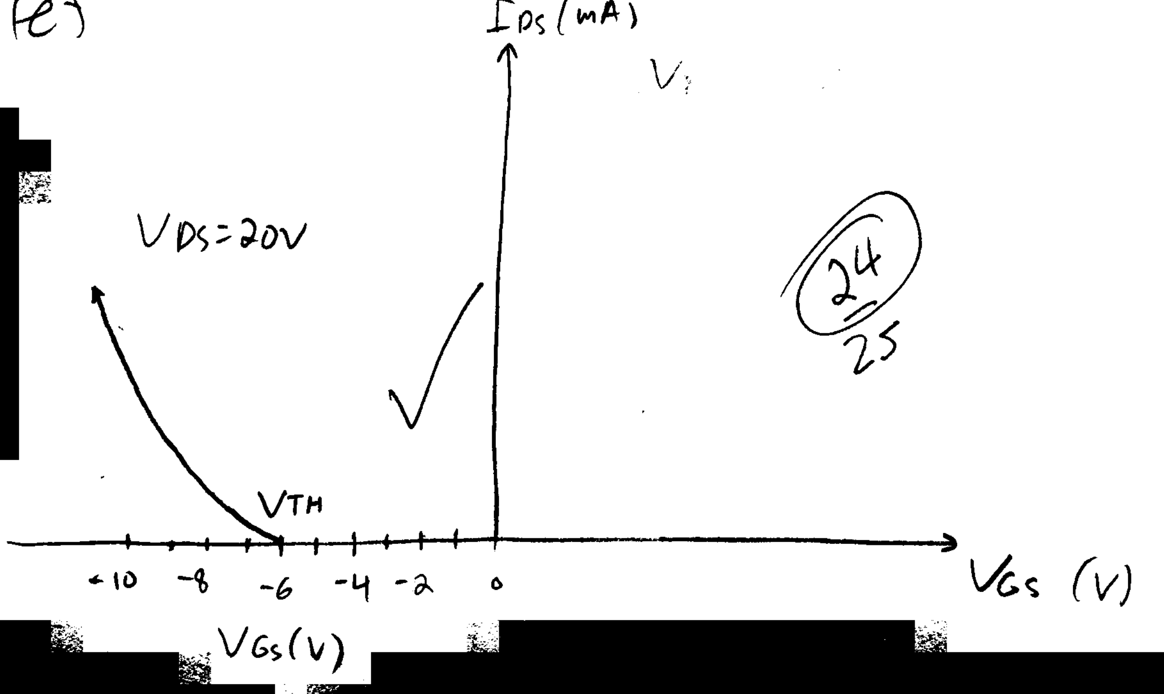
(d)



$V_{DS(sat)}$ is the voltage where

$V_{GS} - V_{GD} = V_{th}$

(e)



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[25] **4.** Using clearly labeled diagrams explain and discuss the principle of operation and characteristics of LEDs, including heterojunction LEDs. Your explanations and discussions must include, the *heterojunction* band diagrams under zero and forward bias, recombination regions, *I-V*, optical power vs. current and output spectrum sketches and how the output spectrum is related to the energy concentrations of electrons and holes in the conduction and valence bands . What is the spectral width of the LED emissions in terms of photon energy spread? How does this change with temperature and bandgap energy? Derive a relationship between the spectral width $\Delta\lambda$ of the emission from an LED and its operating (peak) wavelength λ in terms of temperature and fundamental constants only.