Review of Bipolar Junction Transistors

INEL 4207 Digital Electronics

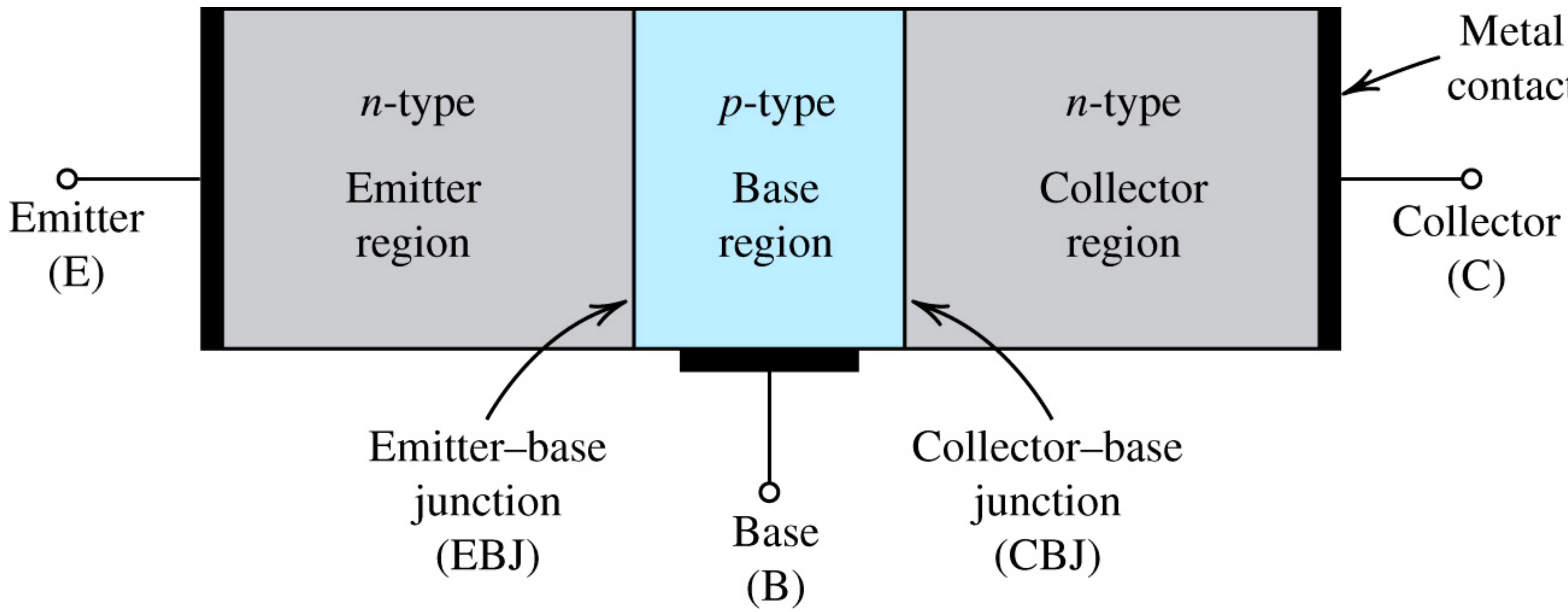
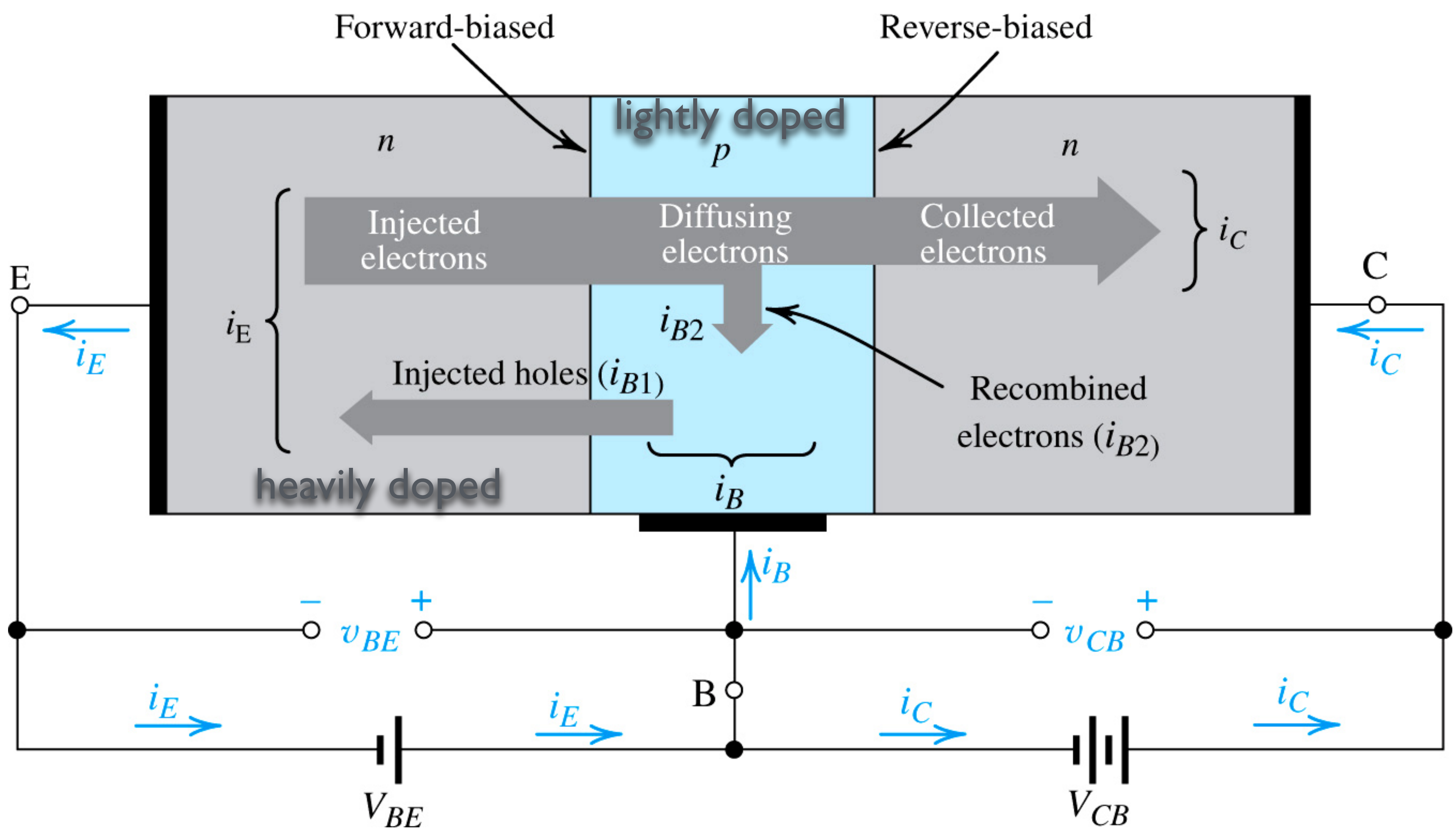


Figure 6.1: A simplified structure of the *npn* transistor.

Modes of operation

	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward



Forward-biased
Reverse-biased
lightly doped
n
p
n
Injected electrons
Diffusing electrons
Collected electrons
i_C
E
C
i_E
i_{B2}
Injected holes (i_{B1})
Recombined electrons (i_{B2})
heavily doped
i_B
v_{BE}
v_{CB}
B
V_{BE}
V_{CB}

Current flow

- **emitter current** (i_E) – is current which flows across EBJ
  - Flows “out” of emitter lead
- **minority carriers** – in *p*-type region.
  - These electrons will be injected from emitter into base.
  - Opposite direction (in relation to conventional current).
- Because base is thin, concentration of excess minority carriers within it will exhibit constant gradient.

$n_p(x)$ = concentration of minority carriers a position x (where 0 represents EBJ boundary)
n_{p0} = thermal-equilibrium value of minority carrier (electron) concentration in base region
v_{BE} = voltage applied across base-emitter junction
V_T = thermal voltage (constant)

$$\text{(eq6.1)}\quad n_p(0) = n_{p0} e^{v_{BE}/V_T}$$

Straight line represents constant gradient.

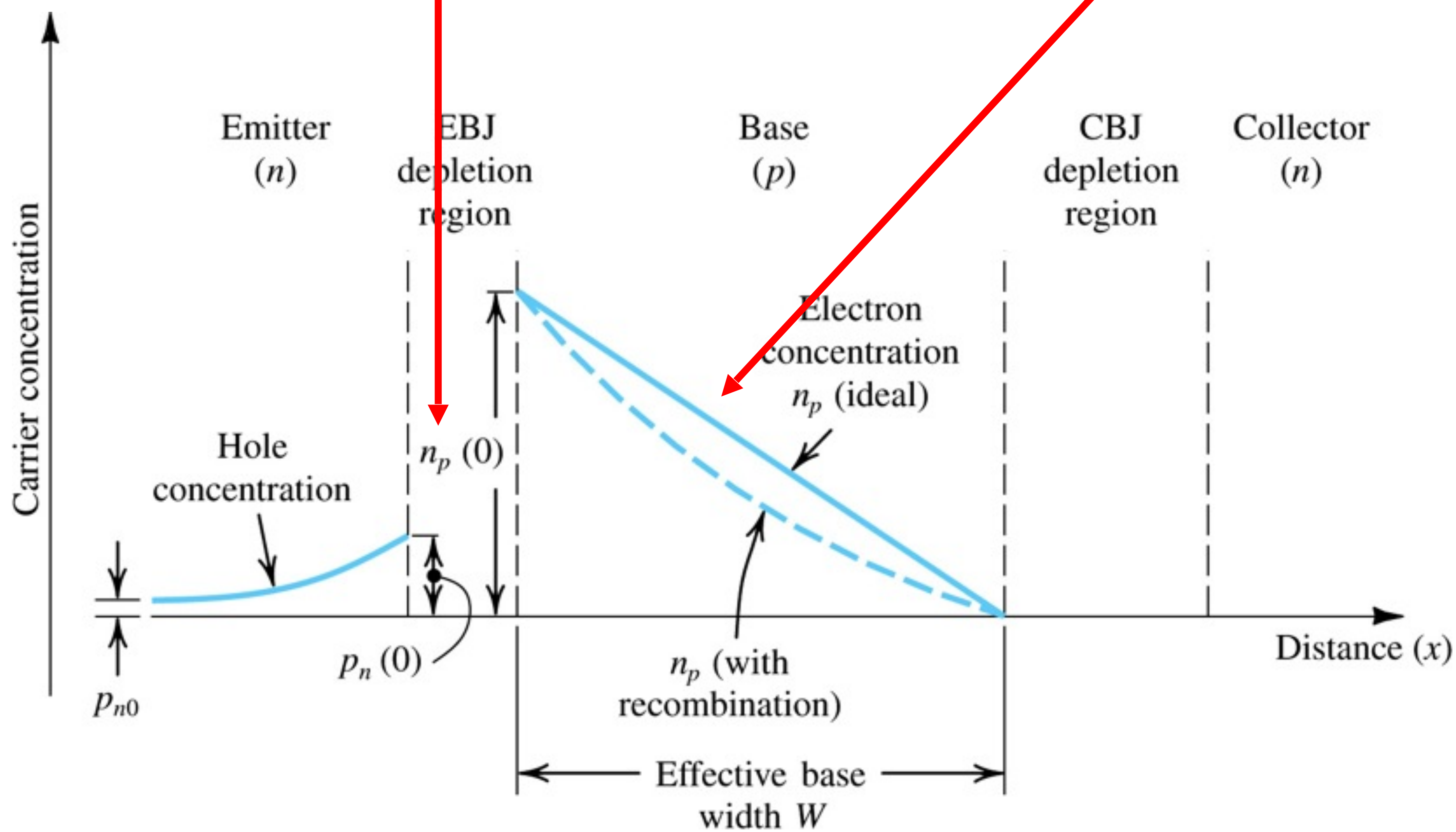


Figure 6.4 Profiles of minority-carrier concentrations in the base and in the emitter of an *npn* transistor operating in the active mode: $v_{BE} > 0$ and $v_{CB} \geq 0$.

Current Flow

- Tapered minority-carrier concentration profile exists.
- It causes electrons injected into base to diffuse through base toward collector.
- As such, electron diffusion current (I_n) exists.

A_E =cross-sectiona area of the base-emitter junction
q= magnitude of the electron charge
D_n = electron diffusivity in base
W= width of base

$$\text{(eq6.2)}\ I_n = A_E q D_n \frac{dn_p(x)}{dx}$$

$$\text{(eq6.2)}\ I_n = A_E q D_n \left(\frac{-dn_p(0)}{W} \right)$$

this simplification may be made if gradient assumed to be straight line

Current Flow

- Some "diffusing" electrons will combine with holes (majority carriers in base).
- Base is thin, however, and recombination is minimal.
- Recombination does, however, cause gradient to take slightly curved shape.
  - The straight line is assumed.

BJT basic equations

$$i_C = I_S e^{v_{BE}/V_T}$$

$$I_S = \frac{A_E q D_n n_{p0}}{W} = \frac{A_E q D_n n_i^2}{N_A W}$$

$$\beta = \frac{i_C}{i_B} \Rightarrow i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

$$i_E = i_C + i_B = (\beta + 1) i_B = \frac{\beta}{\beta + 1} i_C = \alpha i_C$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

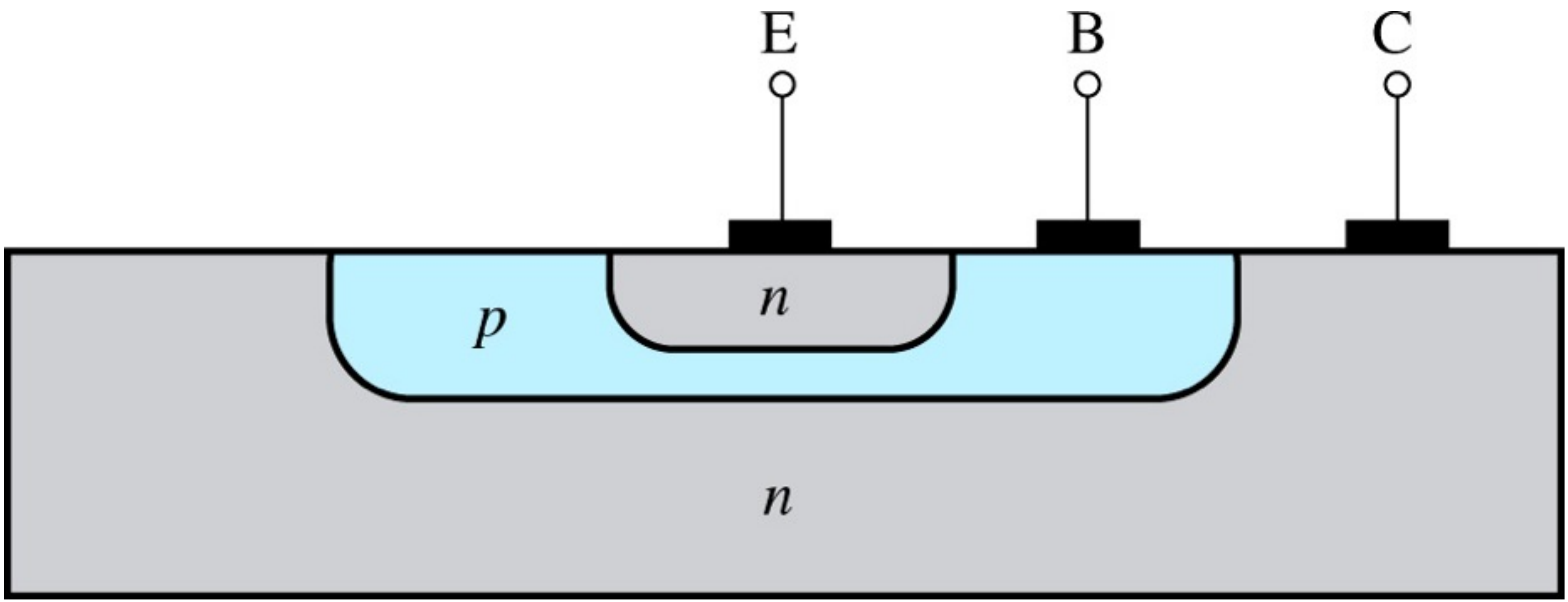


Figure 6.7: Cross-section of an *npn* BJT.

The *pnp* Transistor

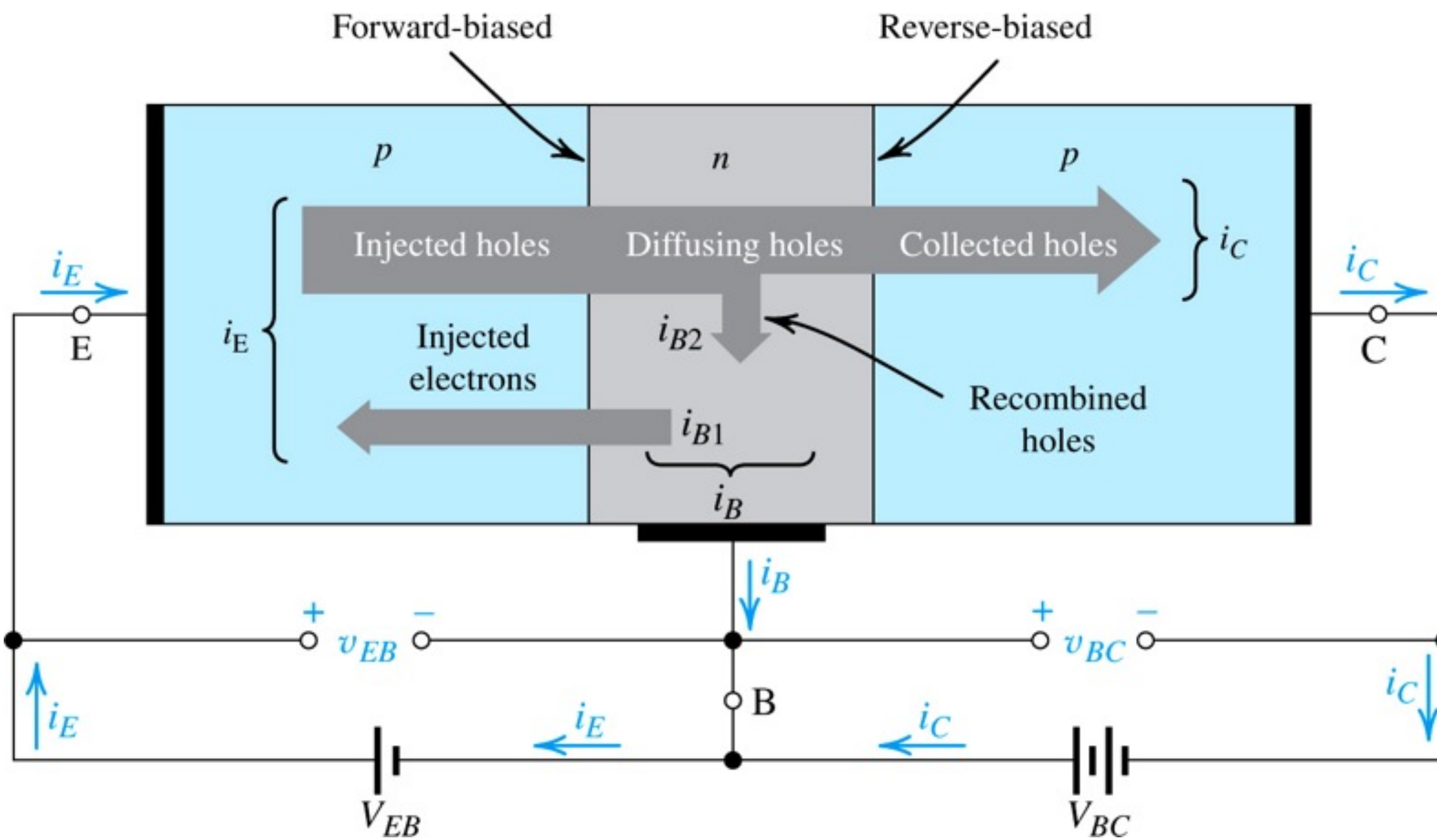


Figure 6.10: Current flow in a *pnp* transistor biased to operate in the active mode.

6.2. **Current-Voltage Characteristics**

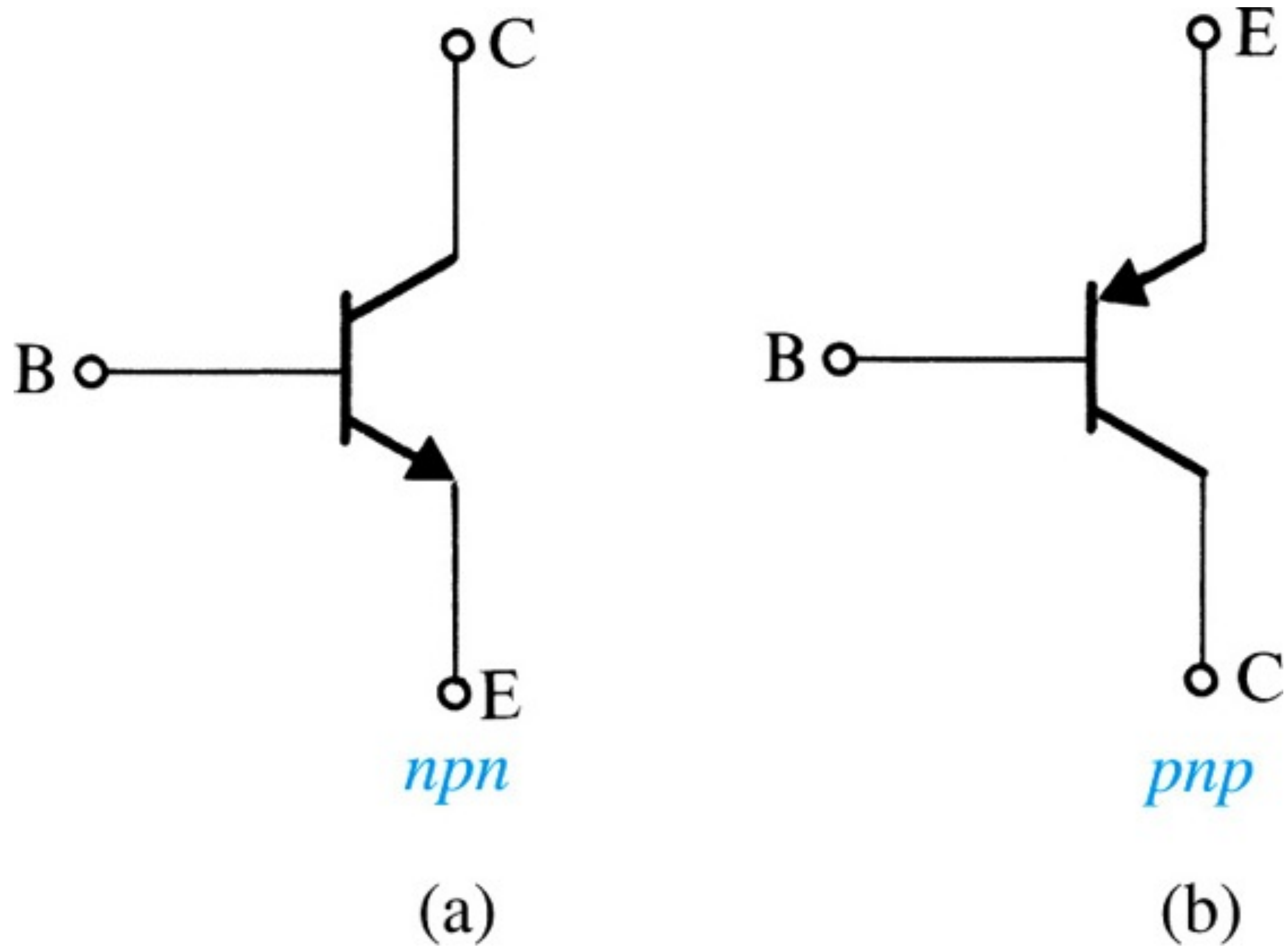


Figure 6.12: Circuit symbols for BJTs.

6.2 Two transistors, fabricated with the same technology but having different junction areas, when operated at a base-emitter voltage of 0.75 V, have collector currents of 0.2 mA and 5 mA. Find I_S for each device. What are the relative junction areas?

6.3 In a particular technology, a small BJT operating at $v_{BE} = 28V_T$ conducts a collector current of 100 μA. What is the corresponding saturation current? For a transistor in the same technology but with an emitter junction that is 32 times larger, what is the saturation current? What current will this transistor conduct at $v_{BE} = 28V_T$? What is the base–emitter voltage of the latter transistor at $i_C = 1$ mA? Assume active-mode operation in all cases.

6.7 Consider an *npn* transistor whose base–emitter drop is 0.76 V at a collector current of 10 mA. What current will it conduct at $v_{BE} = 0.70$ V? What is its base–emitter voltage for $i_C = 10$ μA?

Table 6.2 Summary of the BJT Current–Voltage Relationships in the Active Mode

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

$$i_C = \alpha i_E \qquad i_B = (1 - \alpha) i_E = \frac{i_E}{\beta + 1}$$

$$i_C = \beta i_B \qquad i_E = (\beta + 1) i_B$$

$$\beta = \frac{\alpha}{1 - \alpha} \qquad \alpha = \frac{\beta}{\beta + 1}$$

$$V_T = \text{thermal voltage} = \frac{kT}{q} \simeq 25 \text{ mV at room temperature}$$

Example 6.2

The transistor in the circuit of Fig. 6.14(a) has $\beta = 100$ and exhibits a v_{BE} of 0.7 V at $i_C = 1$ mA. Design the circuit so that a current of 2 mA flows through the collector and a voltage of +5 V appears at the collector.

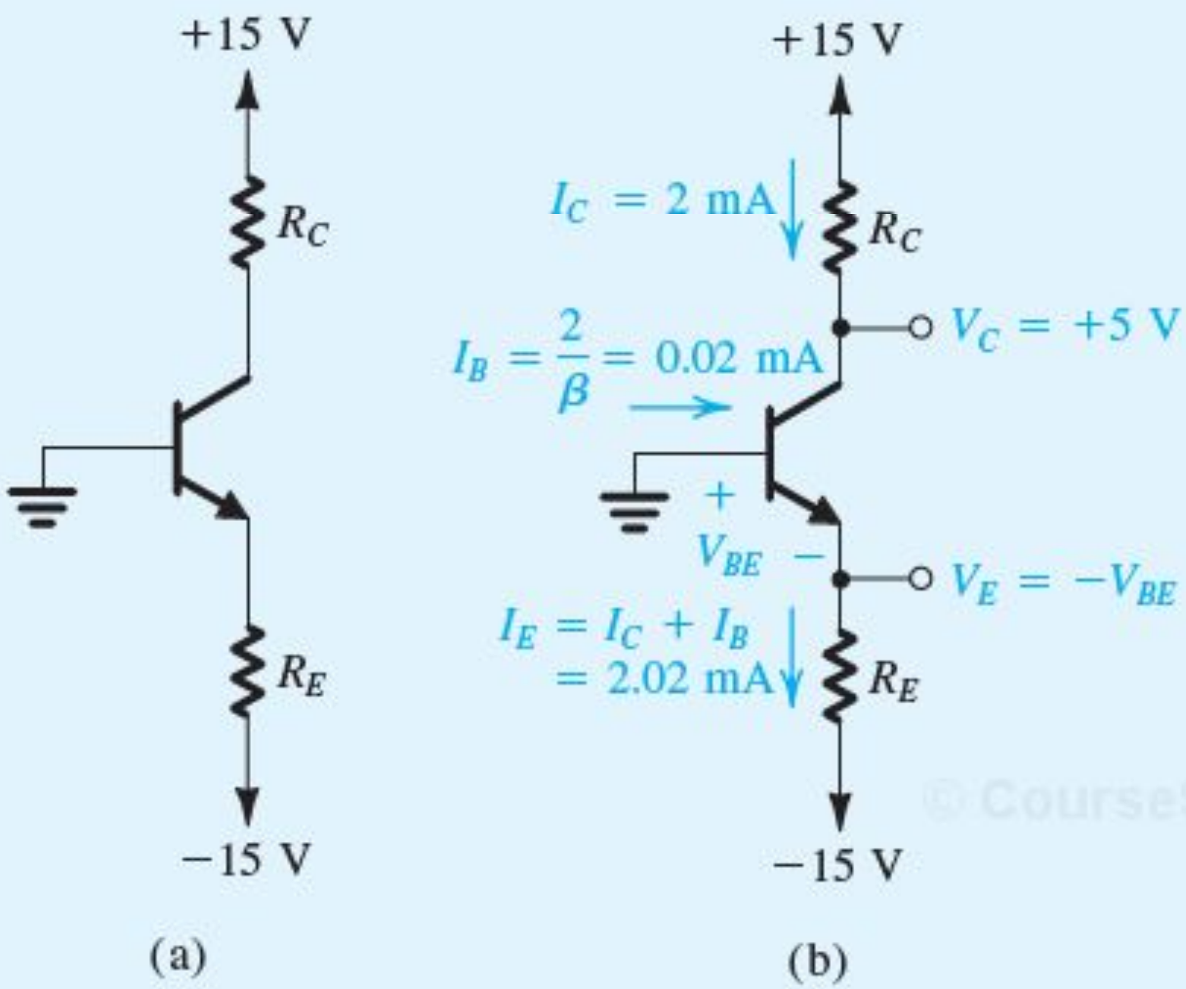
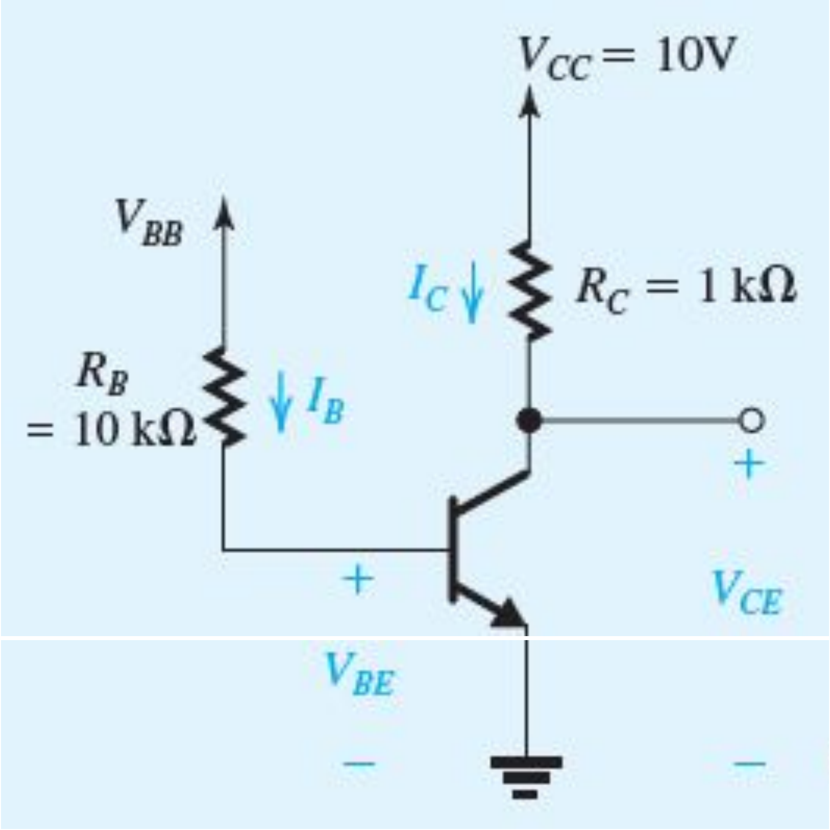


Figure 6.14 Circuit for Example 6.2.

For the circuit in Fig. 6.21, it is required to determine the value of the voltage V_{BB} that results in the transistor operating

(a) in the active mode with $V_{CE} = 5$ V
(b) at the edge of saturation
(c) deep in saturation with $\beta_{forced} = 10$



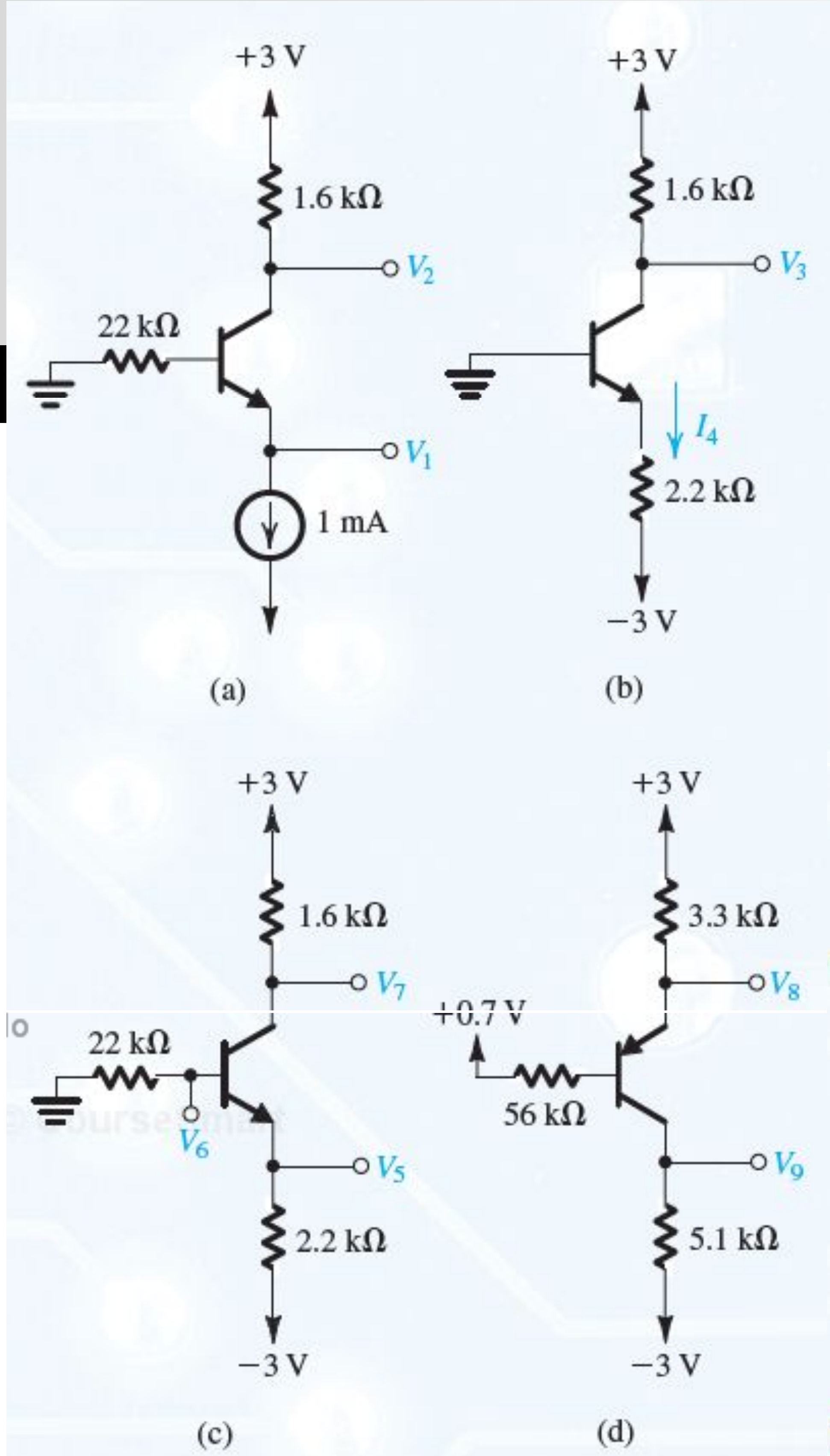
$V_{BE} = 0.7V$

$\beta = 50$

Edge of saturation: $V_{CE} = 0.3V$

Deep in saturation: $V_{CE} = 0.2V$

6.62 For the circuits in Fig. P6.62, find values for the labeled node voltages and branch currents. Assume β to be very high.



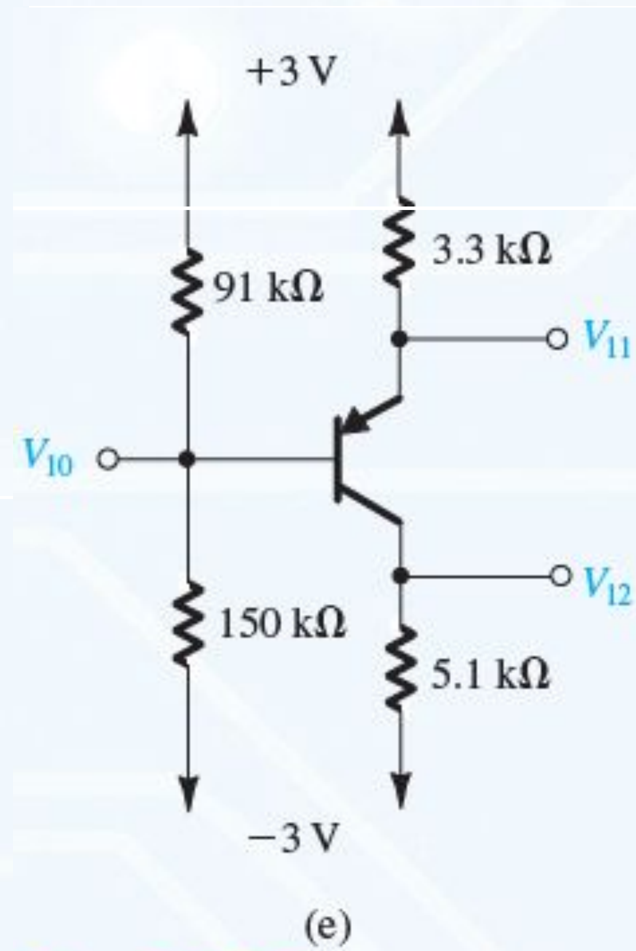


Figure P6.62