Ex.1

The little open circles are connections, in this case to unseen power supplies.

$$V_C = \text{___________}$$
$$R_C = 100 \Omega$$
$$V_B = 0.7 \text{-V}$$
$$V_{BB} = 5 \text{-V}$$
$$I_B = \text{___________}$$

If: $$\beta : = 100$$

$$I_B : = \frac{V_{BB} - 0.7 \text{-V}}{R_B}$$
$$I_B : = 0.86 \text{-mA}$$
$$I_C : = \beta \cdot I_B$$
$$V_C : = V_{CC} - R_C \cdot I_C$$
$$P_Q : = V_C \cdot I_C$$
$$I_C : = 86 \text{-mA}$$
$$V_C : = 3.4 \text{-V}$$
$$P_Q : = 292.4 \text{-mW}$$

If: $$\beta : = 200$$

$$I_B : = \frac{V_{BB} - 0.7 \text{-V}}{R_B}$$
$$I_B : = 0.86 \text{-mA}$$
$$I_C : = \beta \cdot I_B$$
$$V_C : = V_{CC} - R_C \cdot I_C$$
$$P_Q : = V_C \cdot I_C$$
$$I_C : = 172 \text{-mA}$$
$$V_C : = 5.2 \text{-V}$$
$$P_Q : = 584.8 \text{-mW}$$

Since saturation can depend on $$\beta$$, you usually assume a small $$\beta$$ when designing a circuit that should saturate (a switching circuit).

If: $$R_C : = 50 \Omega$$

same $$\beta : = 200$$

Saturation also depends on $$R_C$$ and $$V_{CC}$$.

What is the largest value that $$R_B$$ could be and still keep the transistor in saturation?

$$I_{C_{sat}} : = \frac{V_{CC} - 0.2 \cdot V}{R_C}$$
$$I_{C_{sat}} : = 236 \text{-mA}$$
$$I_B : = \frac{I_{C_{sat}}}{\beta}$$
$$I_B : = 1.18 \text{-mA}$$
$$R_{B_{max}} : = \frac{5 \cdot V - 0.7 \cdot V}{I_B} : = 3.644 \cdot \text{k}$$

Ex.2

$$V_B = \text{___________}$$
$$V_{BB} : = 6 \text{-V}$$
$$I_B = \text{___________}$$
$$I_E = \text{___________}$$
$$V_{CC} : = 10 \text{-V}$$

$$P_Q = ?$$
$$V_E = ?$$
$$V = 6 \text{-V}$$
$$V_E = 5.3 \text{-V}$$
$$R_E = 50 \Omega$$
$$I_E = \frac{V_E}{R_E}$$
$$I_E : = 106 \text{-mA}$$
$$P_Q = ?$$

Doesn't depend on $$\beta$$

$$I_B : = \frac{I_E}{\beta + 1}$$
$$I_B : = 0.5 \text{-mA} \approx \frac{I_E}{\beta} : = 0.53 \text{-mA}$$

$$P_Q = (V_{CC} - V_E) \cdot I_E$$
$$P_Q : = 0.498 \text{-W}$$

If $$\beta$$ is big enough.
**Ex.3** If the load must be connected to ground, a PNP transistor is often a better choice. Let's assume a small $\beta$ and saturation and find the $R_B$ necessary.

\[
\beta = 20
\]

\[
V_C := V_{CC} - 0.2 \cdot V
\]

\[
V_C = 19.8 \cdot V
\]

\[
R_C := 15 \cdot \Omega
\]

\[
I_{Sat} := \frac{V_C}{R_C}
\]

\[
I_{Sat} = 1.32 \cdot A
\]

\[
I_B := \frac{I_{Sat}}{\beta}
\]

\[
I_B = 66 \cdot mA
\]

\[
V_B := V_{CC} - 0.7 \cdot V
\]

\[
V_B = 19.3 \cdot V
\]

\[
R_B := \frac{V_B}{I_B}
\]

\[
R_B = 292 \cdot \Omega
\]

\[
P_Q := 0.2 \cdot V \cdot I_{Sat}
\]

\[
P_Q = 264 \cdot mW
\]

**Ex.4**

Sometimes one transistor can't provide enough amplification. Sometimes you want to "invert" the input (make high off and low on).

Switch open

\[
I_{B1o} := 0 \quad V_{B1o} := 0.7 \cdot V
\]

\[
V_{B2o} := \frac{V_{CC} - 0.7 \cdot V}{R_2}
\]

\[
I_{B2o} = 28.6 \cdot mA
\]

\[
I_{R2o} := I_{B2o}
\]

\[
I_{C2o} := \beta_2 \cdot I_{B2o}
\]

\[
I_{C2o} = 715 \cdot mA
\]

\[
V_{C2o} := V_{CC} - R_C \cdot I_{C2o}
\]

\[
V_{C2o} = -6.45 \cdot V
\]

\[
Q_2 must be in saturation:
\]

\[
I_{C2o} := \frac{V_{CC} - V_{C2o}}{R_C}
\]

\[
I_{C2o} = 493.3 \cdot mA
\]

Switch closed

\[
I_{B1c} := \frac{5 \cdot V - 0.7 \cdot V}{R_B}
\]

\[
I_{B1c} = 1.08 \cdot mA
\]

\[
V_{C1c} := 0.2 \cdot V
\]

\[
I_{C1c} := \frac{V_{CC} - V_{C1c}}{R_2}
\]

\[
I_{C1c} = 29.6 \cdot mA
\]

\[
\beta_1 \cdot I_{B1c} = 86 \cdot mA
\]

\[
I_{C1c} is controlled by R_2
\]

\[
V_{B2c} := V_{C1c}
\]

\[
V_{B2c} = 0.2 \cdot V
\]

\[
I_{B2c} := 0
\]

\[
I_{C2c} := 0 = I_{RCc}
\]

When the switch is open, current flows in through the load resistor, $R_C$. When it is closed, no current flows through the load. This is an example of logical "inversion".
A transistor is used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) Assume the transistor is in saturation (fully on) and that switch has been closed for a long time. What is the load current?

\[ I_C = ? \]

\[ I_{\text{Csat}} = \frac{V_{\text{CC}} - 0.2 \cdot V}{R_L} \quad I_{\text{Csat}} = 600 \cdot mA \]

b) \( \beta = 80 \) find the minimum value of \( V_S \), so that the transistor will be in saturation.

\[ I_{\text{Bmin}} = \frac{I_{\text{Csat}}}{\beta} \quad I_{\text{Bmin}} = 7.5 \cdot mA \]

\[ V_{\text{Smin}} = I_{\text{Bmin}} (R_S + R_1) + 0.7 \cdot V \quad V_{\text{Smin}} = 2.8 \cdot V \]

Use this \( V_S \) for the rest of the problem.

c) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch opens. \( I_{\text{Dmax}} = I_{\text{Csat}} = 600 \cdot mA \)  \( \text{from part a)} \)

d) You got a bad transistor. \( \beta = 60 \) Find the new \( I_C \), and \( V_{CE} \) and \( P_Q \).

\[ I_C = ? \quad I_C = \beta \cdot I_{\text{Bmin}} \quad I_C = 450 \cdot mA \quad \text{Now operating in active region} \]

\[ V_{CE} = ? \quad V_{CE} = V_{\text{CC}} - R_L \cdot I_C \quad V_{CE} = 1.4 \cdot V \]

\[ P_Q = ? \quad P_Q = V_{CE} \cdot I_C \quad P_Q = 0.63 \cdot W \]

\( \beta = 60 \) Use this for the rest of the problem.

c) Find the minimum value of \( R_L \) so that the transistor will be in saturation.

\[ I_B = \frac{V_{\text{Smin}} - 0.7 \cdot V}{R_S + R_1} \quad I_B = 7.5 \cdot mA \]

\[ I_{\text{Cmax}} = \beta \cdot I_B \quad I_{\text{Cmax}} = 450 \cdot mA \]

\[ R_{Lmin} = \frac{V_{\text{CC}} - 0.2 \cdot V}{I_{\text{Cmax}}} \quad R_{Lmin} = 10.7 \cdot \Omega \]

d) \( R_L \), can't be changed, so find the maximum value of \( R_1 \) so that the transistor will be in saturation.

\[ I_{\text{Csat}} = 600 \cdot mA \quad \text{from part a)} \]

\[ I_{\text{Bmin}} = \frac{I_{\text{Csat}}}{\beta} \quad I_{\text{Bmin}} = 10 \cdot mA \]

\[ R_{1\text{max}} = \frac{V_{\text{Smin}} - 0.7 \cdot V}{I_{\text{Bmin}}} - R_S = 10 \cdot \Omega \]
Ex.6  From F05 Final with modifications from F06 Final

A transistor is used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) $\beta := 25$  Assume the transistor is in the active region, find $I_{sw}$, $I_L$, $V_L$, $V_{EC}$ and $P_Q$.

\[
\begin{align*}
I_B &= \frac{V_S - 0.7\, V}{R_S + R_1} \quad I_B = 18.6\, mA = I_{sw} \\
I_L &= \beta \cdot I_B \quad I_L = 465\, mA \\
R_L &= 10\, \Omega \\
V_L &= I_L \cdot R_L \quad V_L = 4.65\cdot V \\
V_{EC} &= V_S - V_L \quad V_{EC} = 5.35\cdot V \\
P_Q &= V_{EC} \cdot I_L \quad P_Q = 2.488\cdot W \\
\end{align*}
\]

b) Was the transistor actually operating in the active region?  yes  no  (circle one)  yes

How do you know?  (Specifically show a value which is or is not within a correct range.)  $V_{EC} = 5.35\cdot V > 0.2\, V$

c)  Find the maximum value of $R_1$, so that the transistor will be in saturation.

If saturated:  $V_{EC} := 0.2\, V$

\[
\begin{align*}
I_{C_{sat}} &= \frac{V_S - 0.2\, V}{R_L} \quad I_{C_{sat}} = 0.98\, A \\
I_{B_{min}} &= \frac{I_{C_{sat}}}{\beta} \quad I_{B_{min}} = 39.2\, mA \\
R_{1_{max}} &= \frac{V_S - 0.7\, V}{I_{B_{min}}} - R_S = -63\, \Omega  \quad \text{NOT POSSIBLE}
\end{align*}
\]

d) $R_1 = 200\, \Omega$ and can't be changed, find the minimum value of $\beta$ so that the transistor will be in saturation.

\[
\begin{align*}
I_{C_{sat}} &= 0.98\, A \\
\beta_{min} &= \frac{I_{C_{sat}}}{I_B} \quad \beta_{min} = 52.7
\end{align*}
\]

e) How much power is dissipated by the transistor if it has the $\beta$ you found in part d)

\[
P_Q := 0.2 \cdot V \cdot I_{C_{sat}} \quad P_Q = 0.196\, W
\]

f) Does the diode in this circuit ever conduct a significant current?  If yes, when and how much?

When the switch opens.  $I_{D_{max}} = I_{C_{sat}} = 0.98\, A$  from part a)

g) The switch is open for a while.  What is the load current ($I_L$) now?  0
Transistor Switching Circuit Examples, p5

Ex.7 From F13 Final

Transistors are used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) In order for current to flow in through the load, the switch should be:
   i) closed or ii) open (Circle one)

b) Assume the switch has been in the position you circled above for a long time. $I_L$ is 1.3A. Find the power dissipated by transistor $Q_2$ (neglect base current and $V_{BE}$).

$$P_{Q2} = V_{CE2}I_L$$

$$V_{CE2} = V_{CC2} - I_LR_L = 1.1\cdot V$$

$$P_{Q2} = 1.43\cdot W$$

c) This is an unacceptable power loss, so you would like to determine the minimum $\beta_2$ needed so that $Q_2$ will be in saturation. Assume $Q_1$ is also in saturation. You may assume $I_E = I_C$ for both transistors.

$$\beta_{2min} = ?$$

You replace $Q_2$ with a new transistor that has a $\beta$ greater than what you just calculated.

d) How much power is dissipated by the new transistor $Q_2$ (neglect base current and $V_{BE}$)?

$$P_{Q2} = ?$$

$$P_{Q2} = 320\cdot mW$$

e) What is the maximum value of $R_1$ needed to saturate $Q_1$?

$$\beta_1 = 100$$

$$I_{B1min} = \frac{I_{C1}}{\beta_1}$$

$$I_{B1min} = 0.575\cdot mA$$

$$V_{B1} = V_{B2} + 0.7\cdot V$$

$$V_{B1} = 6.2\cdot V$$

$$R_{1max} = \frac{V_{CC1} - V_{B1}}{I_{B1min}}$$

$$R_{1max} = 3.13\cdot k\Omega$$

f) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch closes. $I_{Dmax} = I_L = 1.6\cdot A$ from part c)
A couple of transistors are used to control the current flow through an inductive load. The switch has been closed, as shown, for a long time.

a) You measure the voltage at each collector (referenced to ground) as shown on the drawing. Find the power dissipated by transistor $Q_2$.

\[
V_{C1} = 5\cdot V \quad V_{C2} = 2\cdot V \\
I_L = \frac{V_{CC} - 2\cdot V}{R_L} \quad I_L = 1.5\cdot A \\
P_{Q2} = V_{C2}I_L \quad P_{Q2} = 3\cdot W
\]

b) Find the $\beta$ of transistor $Q_2$.

\[
V_{R2} = 5\cdot V - 0.7\cdot V \quad V_{R2} = 4.3\cdot V \\
I_{R2} = \frac{V_{R2}}{R_2} \quad I_{R2} = 43\cdot mA \\
\beta_2 = \frac{I_L}{I_{R2}} \quad \beta_2 = 34.884
\]

c) Find the $\beta$ of transistor $Q_1$.

\[
I_{R1} = \frac{V_{CC} - 0.7\cdot V}{R_1} \quad \beta_1 = \frac{I_{R2}}{I_{R1}} \quad \beta_1 = 58.9
\]

d) Find the minimum $\beta$ for transistor $Q_1$ to be in saturation. $\beta_{1\text{min}} = ?$

If $Q_1$ is saturated: $V_{R2} = V_{CC} - 0.2\cdot V - 0.7\cdot V \quad V_{R2} = 7.1\cdot V$

If $Q_1$ is saturated: $I_{R2} = \frac{V_{R2}}{R_2} \quad I_{R2} = 71\cdot mA \quad \beta_{1\text{min}} = \frac{I_{R2}}{I_{R1}} \quad \beta_{1\text{min}} = 97.3$

You replace $Q_1$ with a different transistor so that now: $\beta_1 = 200$ Use this from now on.

e) Find the new load current ($I_L$) assuming transistor $Q_2$ is in the active region.

$Q_1$ is saturated: $I_{R2} = 71\cdot mA \quad I_L = I_{R2}\beta_2 \quad I_L = 2.477\cdot A$

f) Check the assumption that $Q_2$ is in the active region and recalculate $I_L$ if necessary.

$\beta_{2\text{min}} = \frac{9.907\cdot V}{2.477\cdot A} \quad \beta_{2\text{min}} = 4.01$

$Q_2$ is saturated: $I_L = \frac{V_{CC} - 0.2\cdot V}{R_L} \quad I_L = 1.95\cdot A$

$V_{CE2} = \frac{V_{CC} - I_{R2}\beta_2 - R_L}{R_2} \quad V_{CE2} = -1.907\cdot V$ Not possible

g) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch opens. $I_{D_{\text{max}}} = 1.95\cdot A$ from part f)