Physics 261
Exam 2

Remember to show your work.
45 points possible.
1. (5 points) At what current $i$ does the diode turn on?

Imagine increasing $i$ until the diode turns on. So $i_D = 0$ and $i_R = i$. Voltage across diode is then $V_D = iR$. To turn on, we require $V_D$ to reach $V_T$, so $iR = V_T$.

$$i = \frac{V_T}{R}.$$
2. (15 points) Assume $\beta = 100$ and $V_T = 0.7 \, V$.

(a) Assuming active mode, find $i_B$ and $i_C$, and $V_{out}$ in terms of $V_{in}$.

(b) Find the gain and offset.

(c) For what values of $V_{in}$ is the transistor in cutoff mode?

(d) For what values of $V_{in}$ is the transistor in saturation mode?

(a) 
\[ i_B = \frac{(V_{in} - 0.7 \, V)}{100 \, \Omega} = \frac{V_{in}}{100 \, \Omega} - 7 \, mA \]
\[ i_C = \beta i_B = \frac{V_{in}}{100 \, \Omega} - 70 \, mA \]
\[ V_{out} = 10 \, V - i_C \cdot 100 \, \Omega = 10 \, V - (V_{in} - 0.7 \, V) = 10.7 \, V - V_{in} \]

(b) Reading off the result in (a), gain = -1, offset = 10.7 \, V.

(c) Cutoff: $V_{in} < 0.7 \, V$

(d) Saturation: If we cannot get $i_C$ equal to solution in (a) because of the fundamental maximum $10 \, V / 100 \, \Omega = i_{C\, \text{max}}$, then we have saturation:
\[ \frac{V_{in}}{100 \, \Omega} - 70 \, mA > \frac{10 \, V}{100 \, \Omega} \]
\[ \text{i.e., } V_{in} > 10.7 \, V \]
3. (20 points) In this variation on the Schmitt trigger, the comparator’s lower rail is at ground. Let’s analyze it from scratch.

(a) Solve for $V_+$ in terms of $V_{in}$ and $V_{out}$.
(b) If $V_+ > 0$, what is $V_{out}$?
(c) Combine the results of parts a & b. Solve for a condition on $V_{in}$ in terms of $V_s$ only.
(d) If $V_+ < 0$, what is $V_{out}$?
(e) Combine the results of parts a & d. Solve for a condition on $V_{in}$ in terms of $V_s$ only.
(f) Sketch the relationship of $V_{out}$ to $V_{in}$.

\[
\frac{V_{in} - V_+}{R} + \frac{V_{out} - V_+}{R} = 0 \quad \Rightarrow \quad V_+ = \frac{1}{2} (V_{in} + V_{out})
\]

\[
\text{IF } V_+ > 0 \text{ THEN } V_+ > V_- \quad \text{SO } V_{out} \rightarrow V_s.
\]

\[
\frac{1}{2} (V_{in} + V_{out}) > 0 \quad \Rightarrow \quad \frac{1}{2} (V_{in} + V_s) > 0 \quad \Rightarrow \quad V_{in} > -V_s
\]

\[
V_+ < 0 \quad \Rightarrow \quad V_+ < V_- \quad \Rightarrow \quad V_{out} \rightarrow 0
\]

\[
\frac{1}{2} (V_{in} + V_{out}) < 0 \quad \Rightarrow \quad \frac{1}{2} (V_{in} + 0) < 0 \quad \Rightarrow \quad V_{in} < 0
\]

\[
\rightarrow V_{in}
\]

\[
\rightarrow V_s
\]
4. (5 points) Match each circuit diagram with the appropriate description and equation. In the equations, $a$ and $b$ are positive constants. One example is done for you.

- $V_{out} = -aV_1 - bV_2$ (inverting adder)
- $V_{out} = aV_1 + bV_2$ (non-inverting adder)
- $V_{out} = aV_1$ (non-inverting amplifier)
- $V_{out} = V_1$ (follower, buffer)
- $V_{out} = -aV_1$ (inverting amplifier)
- $V_{out} = aV_1 - bV_2$ (subtractor)