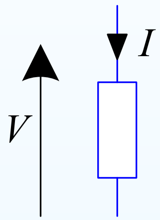
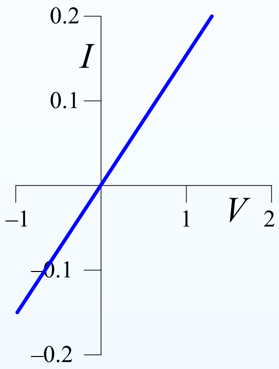
8: Nonlinear Components

Ideal Diode

The *characteristic* of a component is a plot of I against V using the passive sign convention.

All our components have had straight-line characteristics.





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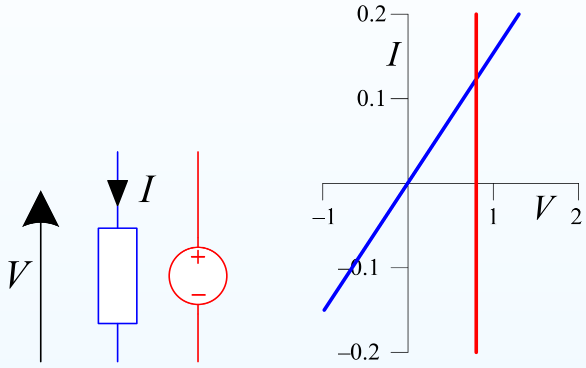

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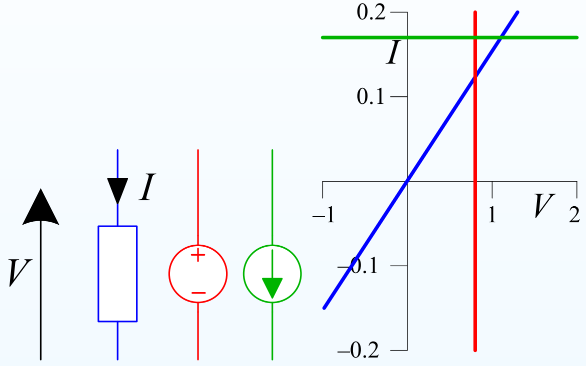

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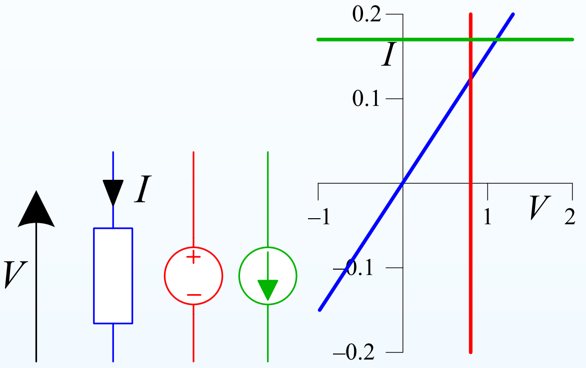

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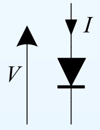
An ideal *diode* allows current to flow in one direction only.



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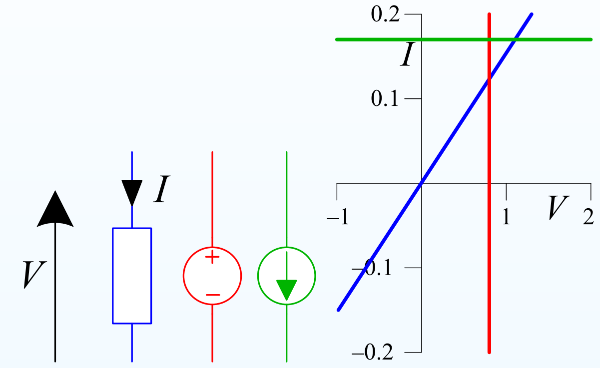

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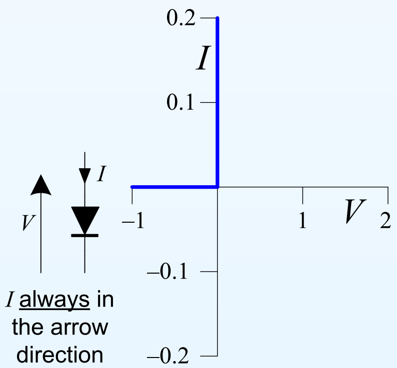

Its characteristic is not a straight line, but is made from two straight line segments: *piecewise-linear* .

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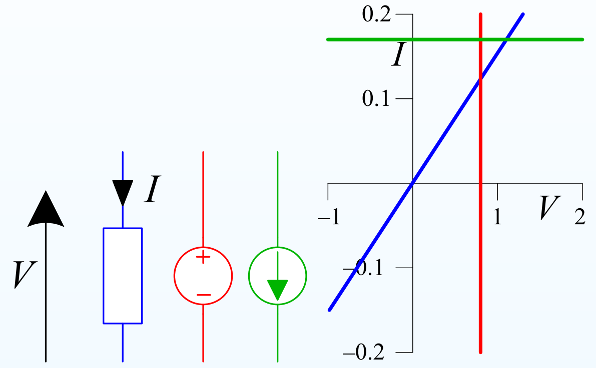
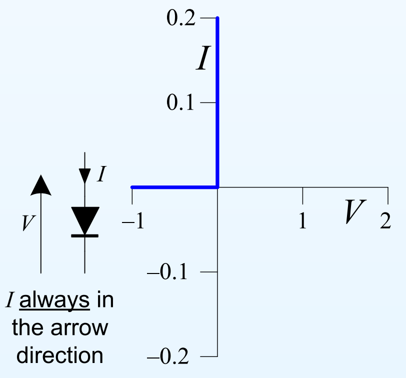


An ideal *diode* allows current to flow in one direction only.

Its characteristic is not a straight line, but is made from two straight line segments: *piecewise-linear*. Each segment is a *mode of operation*.



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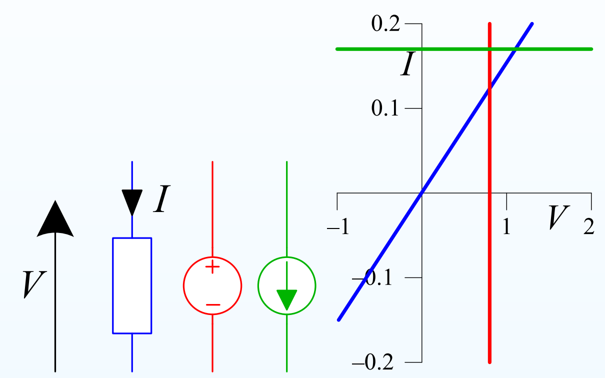

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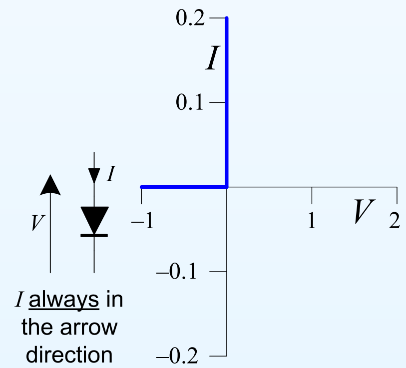

Each mode applies only when a particular condition is true:

Mode	Condition	Equation
Conducting (or “forward bias” or “on”)	$I > 0$	$V = 0$
Non-conducting (or “reverse bias” or “off”)	$V < 0$	$I = 0$

Operating modes

To analyse a circuit with a diode in it, you first guess which mode it is operating in, solve the circuit and then check the condition.
If you guessed wrongly, the condition will not be met.

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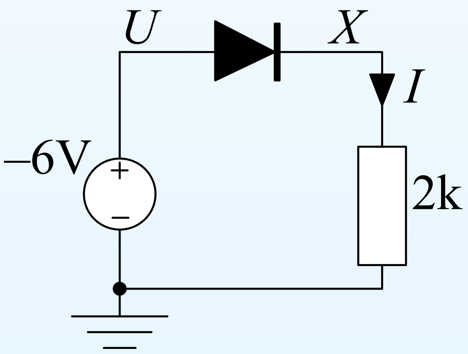

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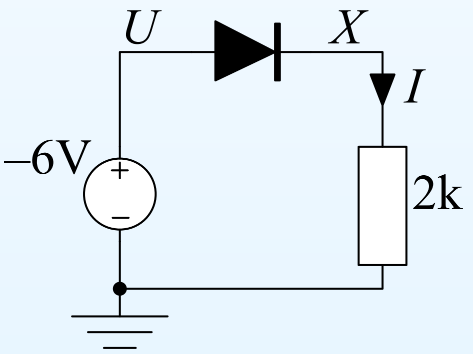

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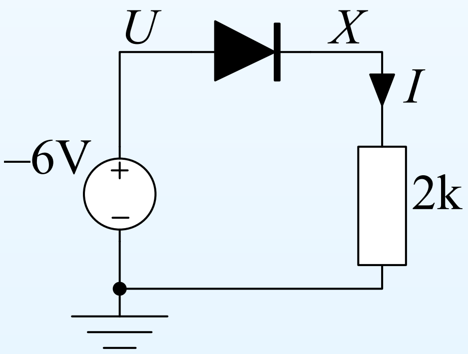

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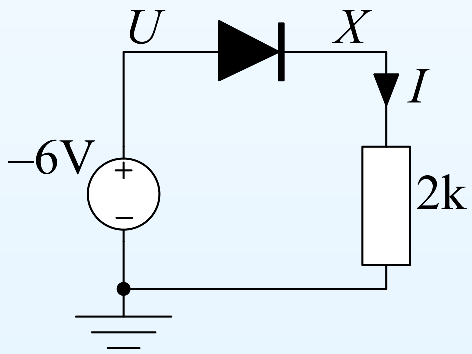

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$V_D = 0 \Rightarrow X = U = -6$

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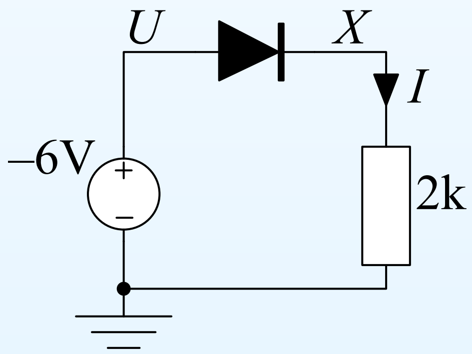

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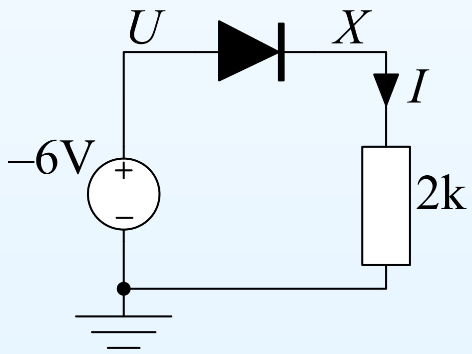

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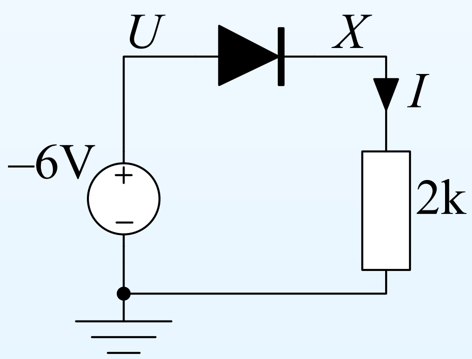

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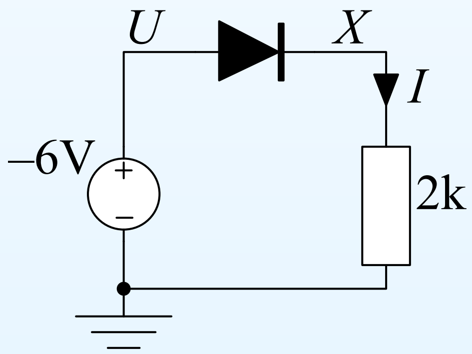

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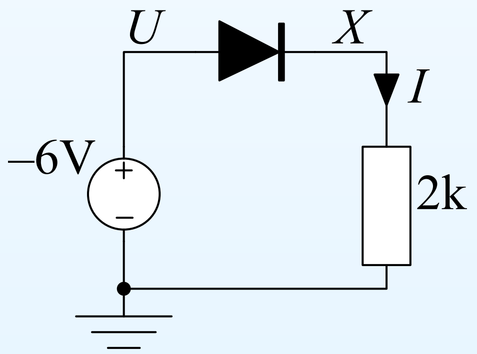

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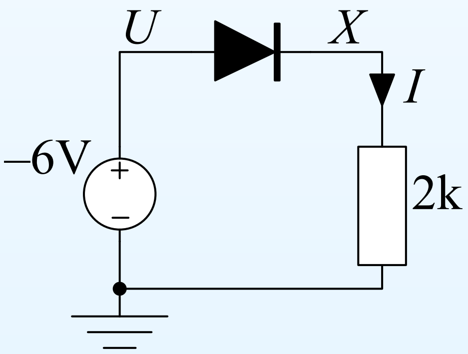

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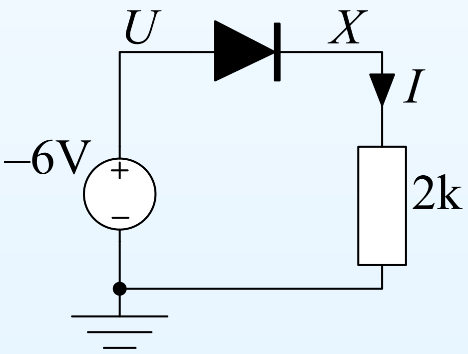

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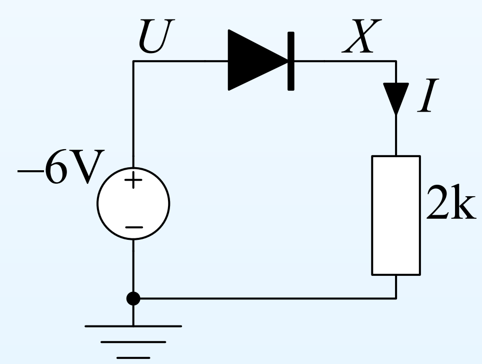

Assume Conducting Mode $\Rightarrow V_D = 0$

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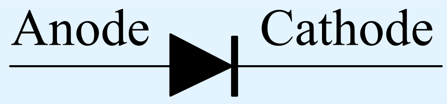
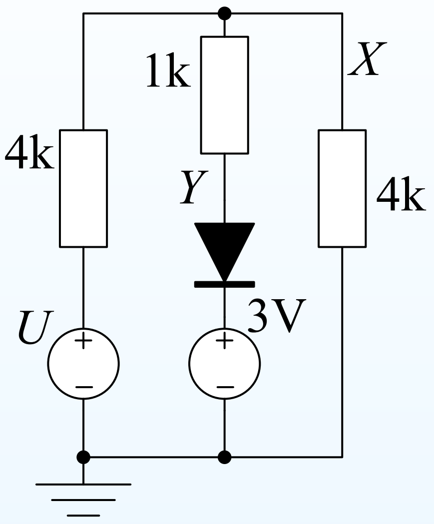


Current flows from *anode* to *cathode*.

Switching Point

How does X change with U ?



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Voltage across diode is $V_D = Y - 3$.
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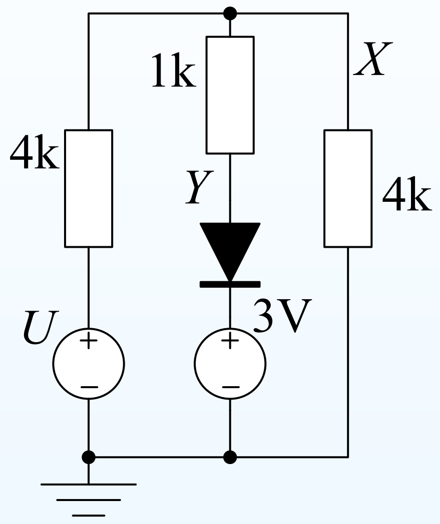

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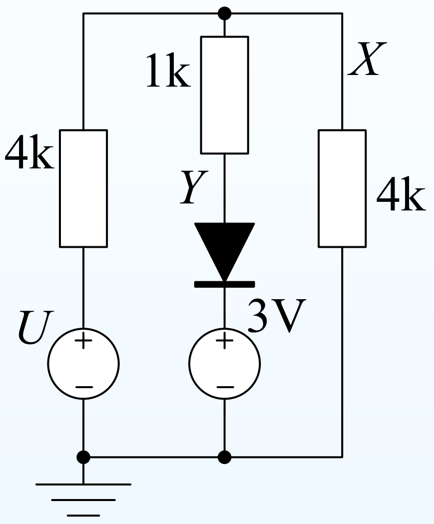

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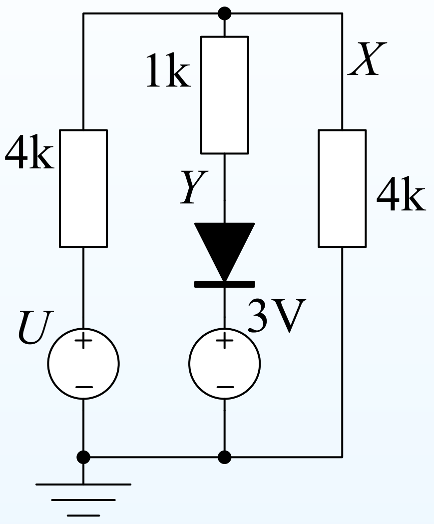

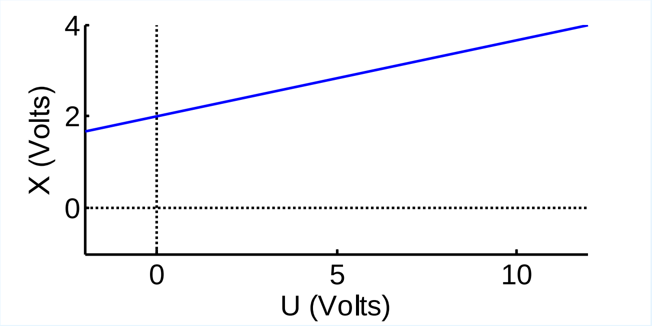

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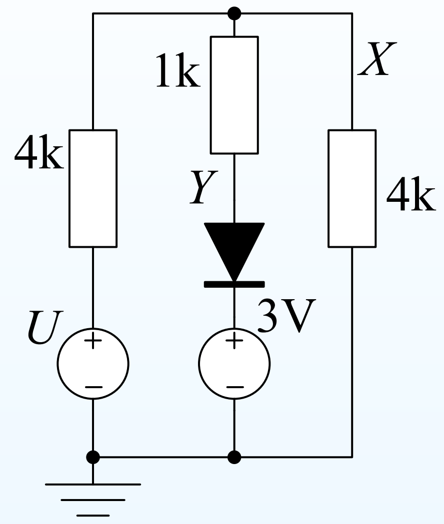

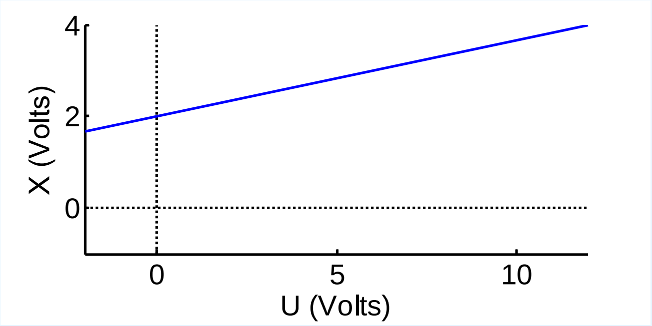

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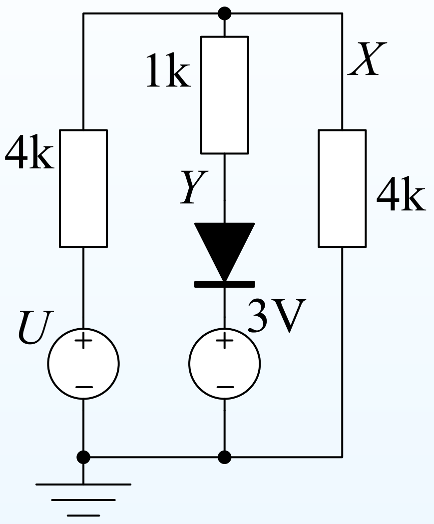
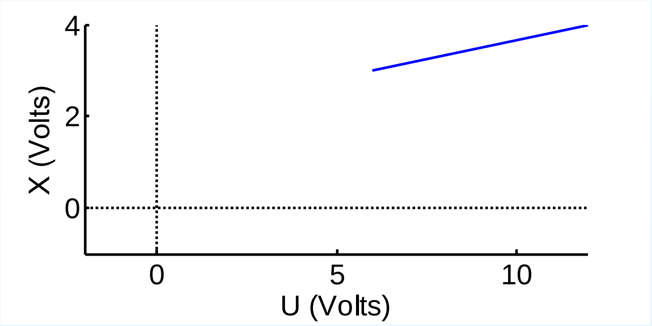
$I_D > 0 \Leftrightarrow U > 6$





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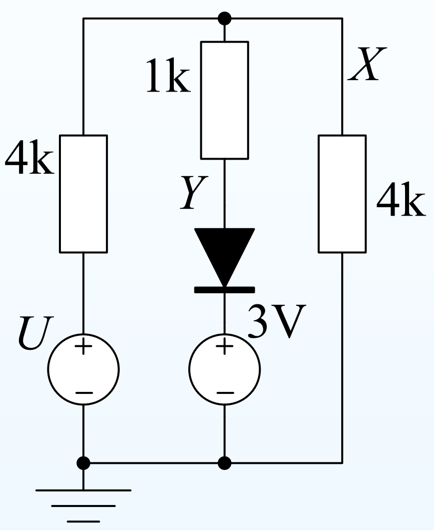

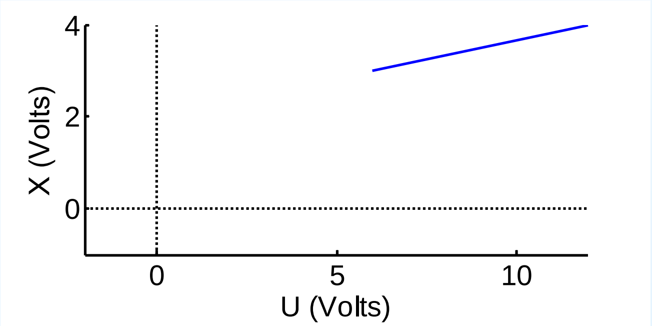

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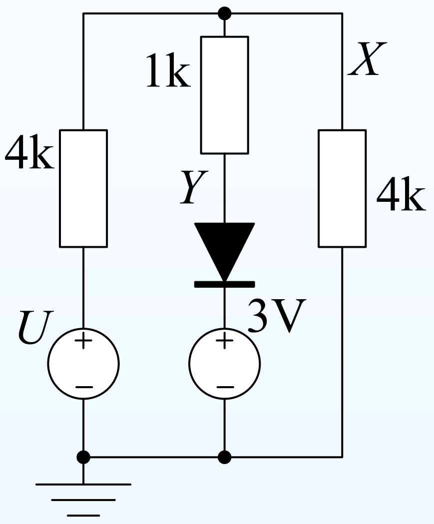

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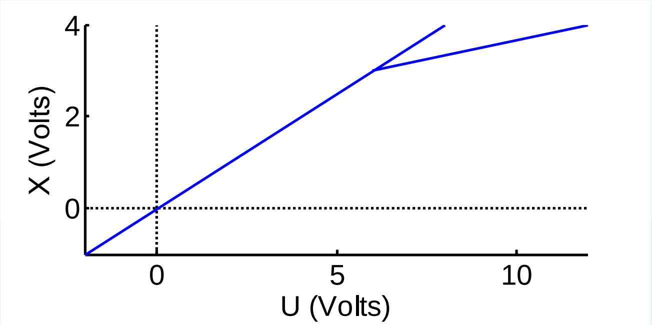
Potential Div: $X = Y = \frac{1}{2}U$



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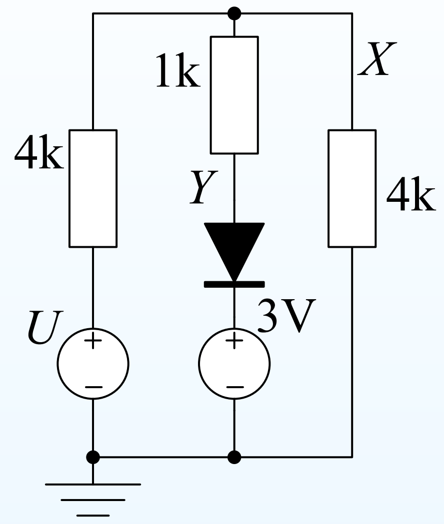

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Potential Div: $X = Y = \frac{1}{2}U$
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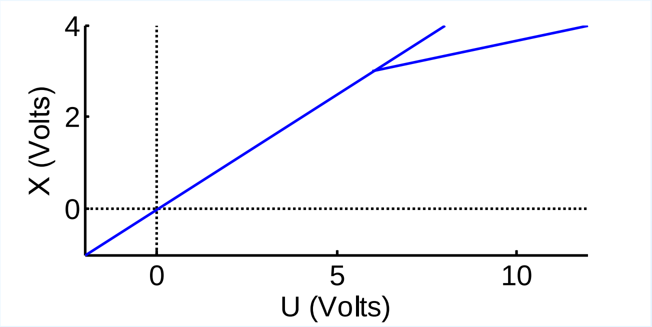
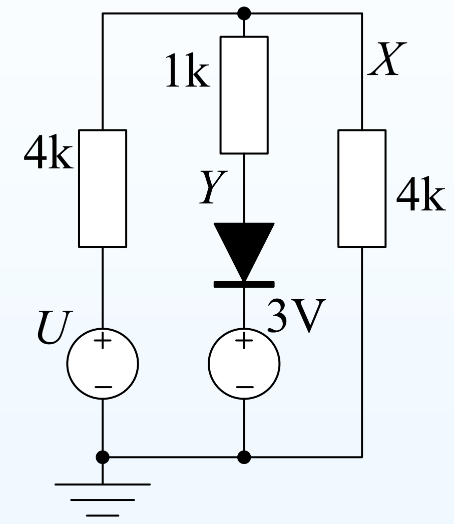


Switching Point

How does X change with U ?



Voltage across diode is $V_D = Y - 3$.
Current through diode is $I_D = \frac{X-Y}{1}$ mA.

Assume Conducting Mode $\Rightarrow Y = 3$

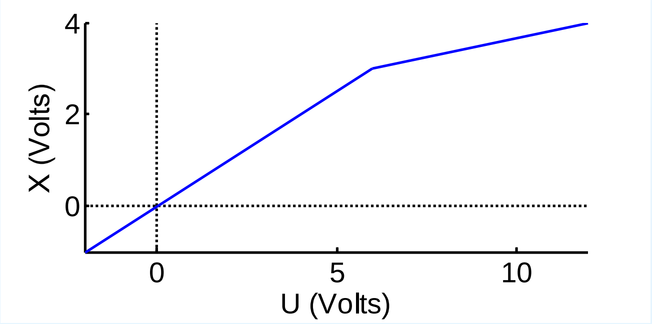
KCL: $\frac{X-U}{4} + \frac{X-3}{1} + \frac{X}{4} = 0$

$\Rightarrow X = \frac{1}{6}U + 2$

$I_D = \frac{X-3}{1} = \frac{1}{6}U - 1$

$I_D > 0 \Leftrightarrow U > 6$

Assume Non-conducting Mode
$\Rightarrow I_D = 0$



Potential Div: $X = Y = \frac{1}{2}U$

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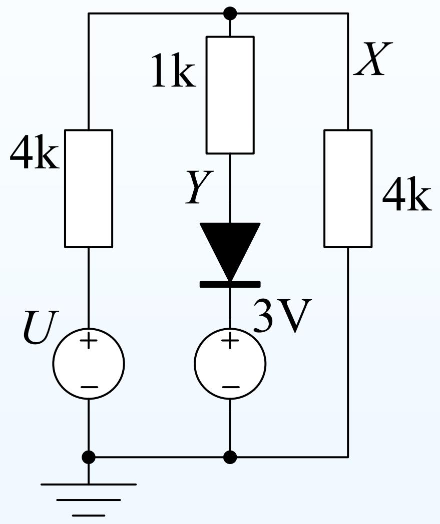

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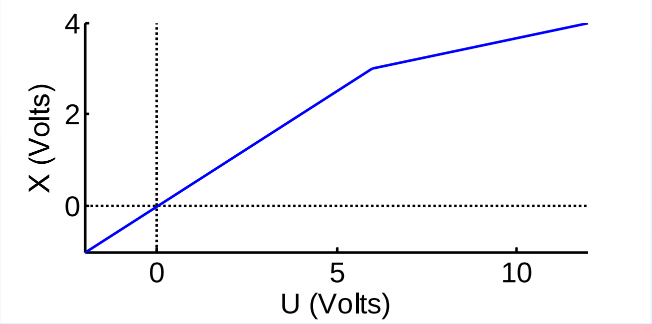

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Diode switches between regions where the graphs intersect $(U = 6)$.
At this point both the diode equations, $V_D = 0$ and $I_D = 0$, are true.

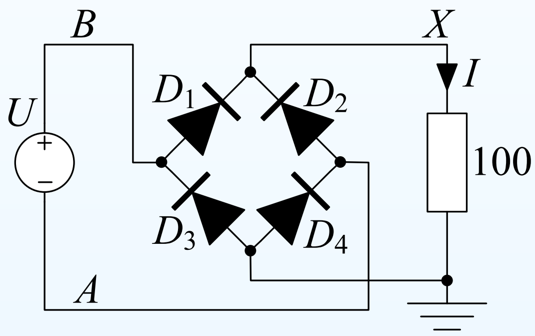
Bridge Rectifier

Bridge Rectifier: 4 diodes:

D_1 and D_2 both point towards node X.

D_3 and D_4 both point away from ground.

The input voltage is $U = B - A$.



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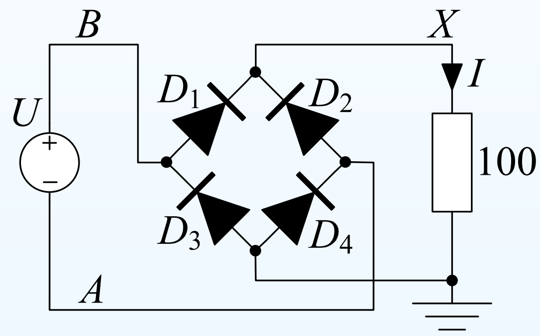

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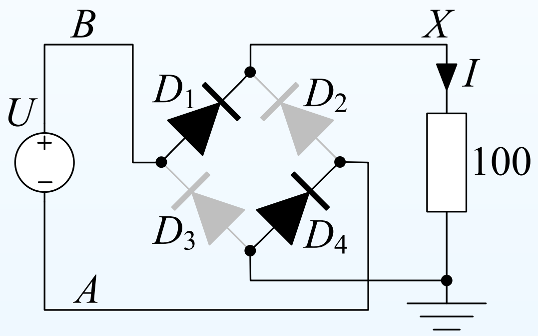

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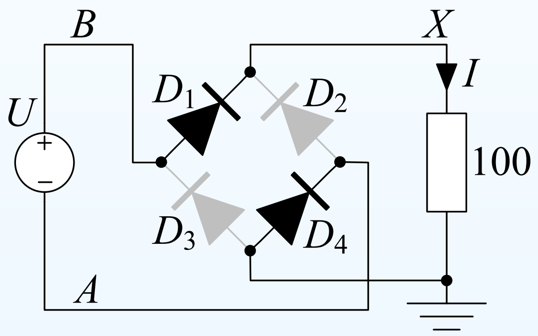

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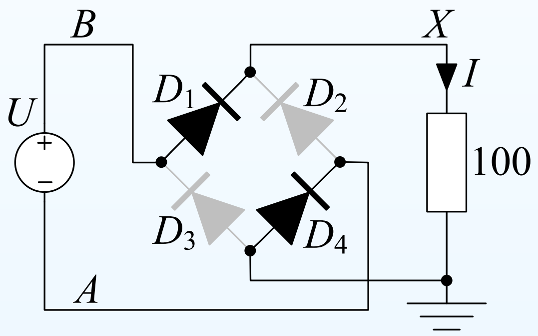

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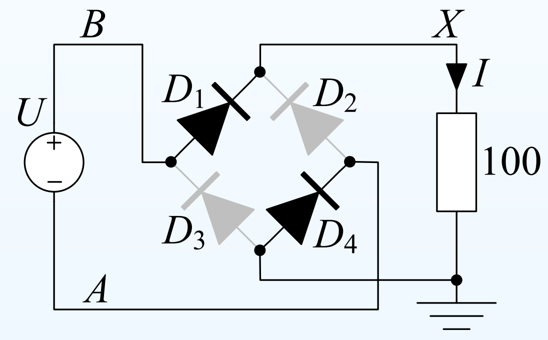

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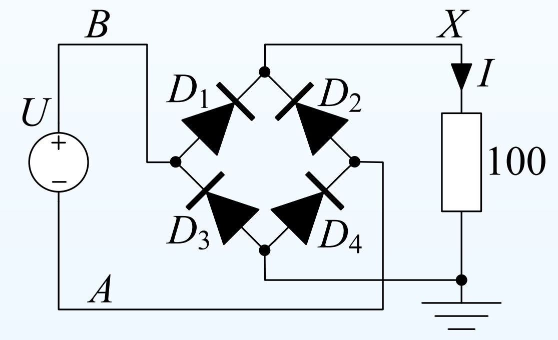

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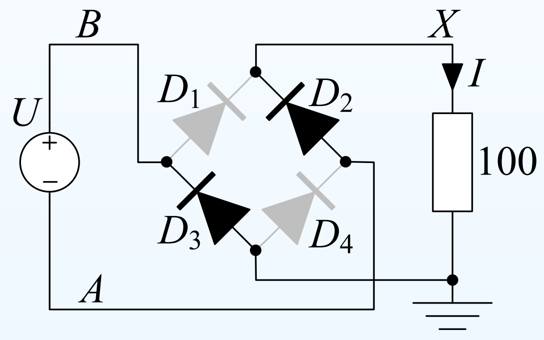

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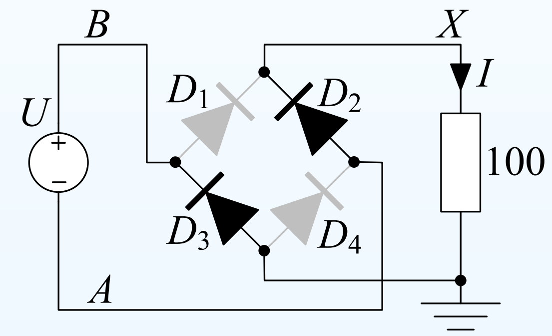

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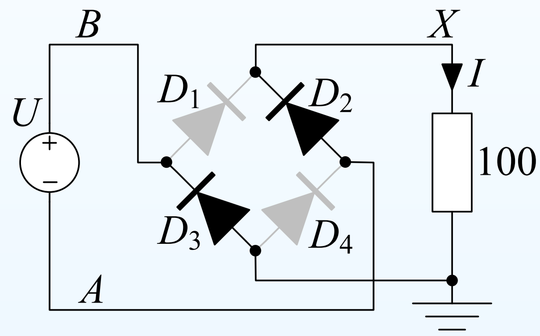

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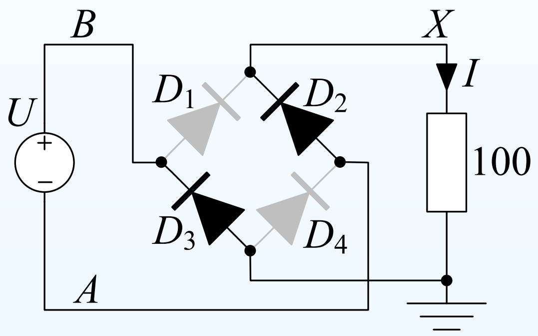

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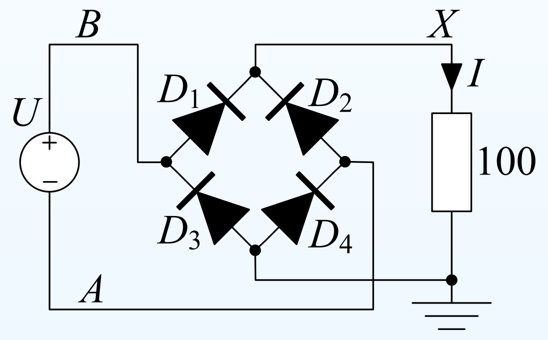

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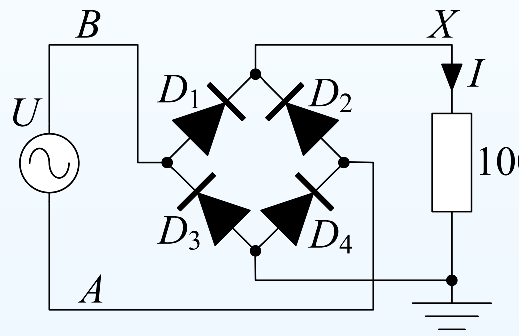

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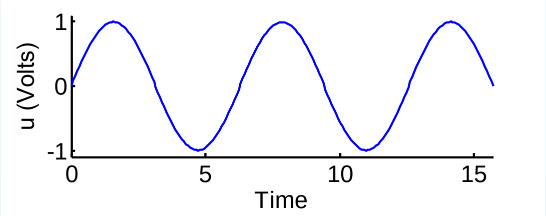

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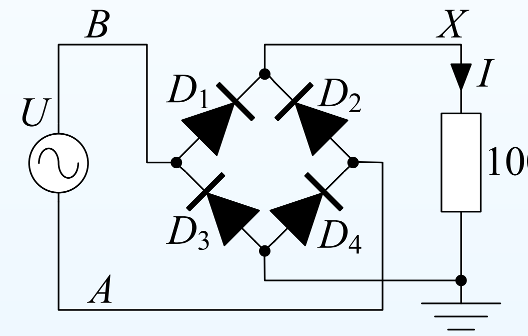

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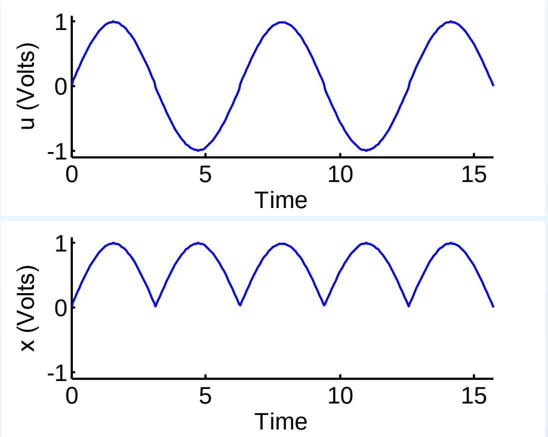
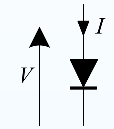


X is always equal to $|U|$: this is an absolute value circuit.

If U is a sine wave, then X is a *full-wave rectified* sine wave with twice the frequency.

Non-Ideal Diode

An *ideal* diode allows has $V = 0$ whenever it is "on".



I always in the arrow direction

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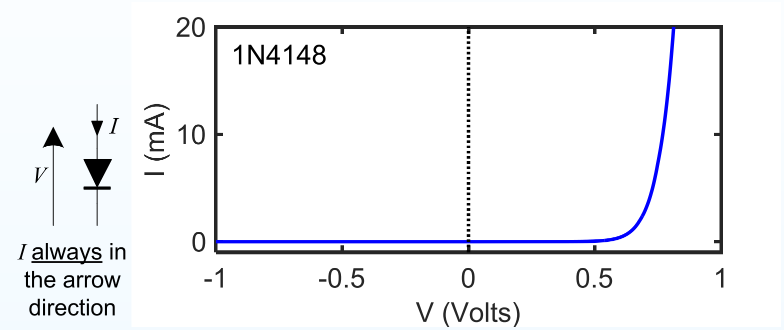

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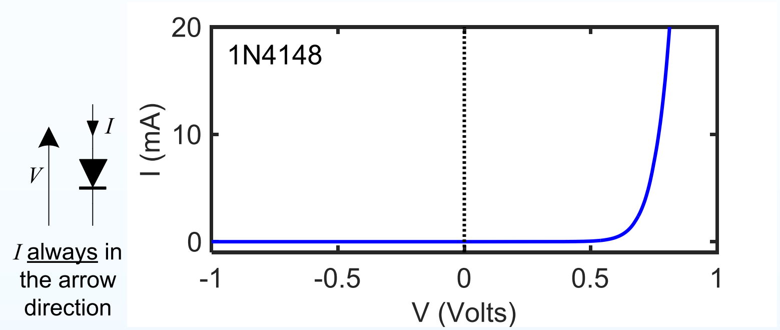

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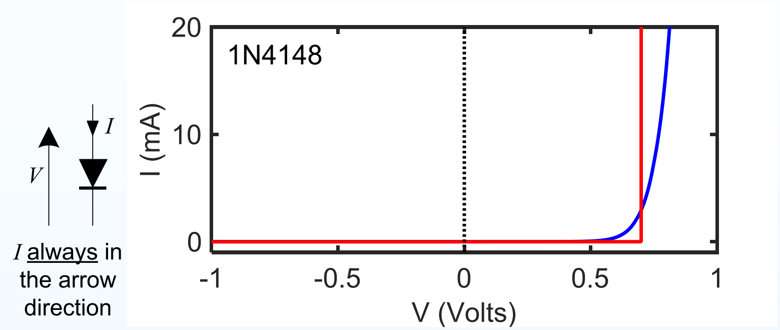

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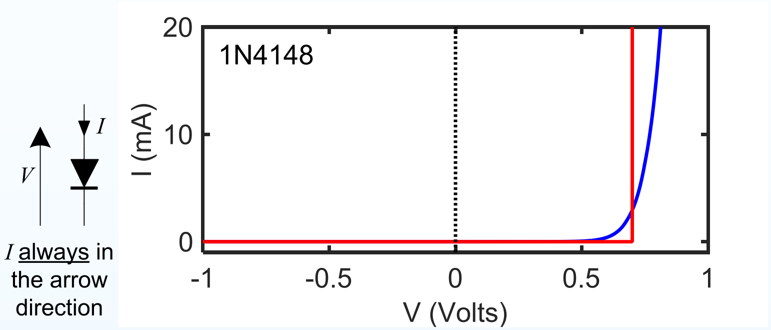

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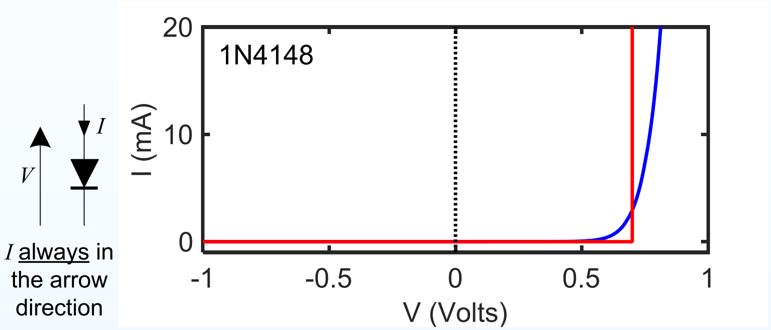

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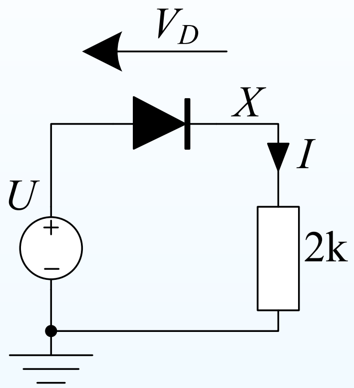
The two regions of operation are now:

Region	Condition	Equation
Conducting Mode ("on")	$I > 0$	$V = 0.7$
Non-conducting Mode ("off")	$V < 0.7$	$I = 0$

Halfwave Rectifier

A halfwave rectifier aims for $X = \max(U, 0)$



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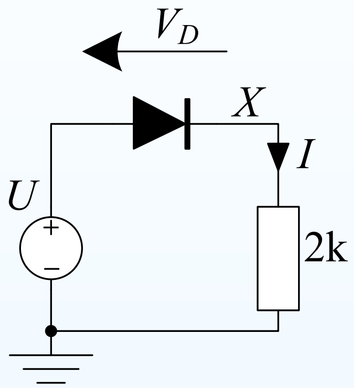

(a) $U > 0.7$

Diode on, $X = U - 0.7$, $I = \frac{U-0.7}{2\,\text{k}} > 0$

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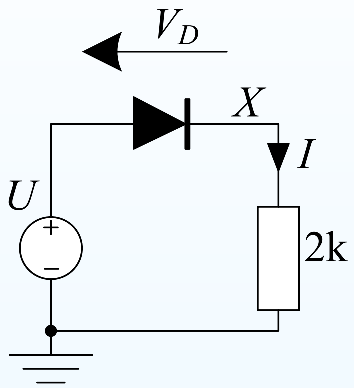

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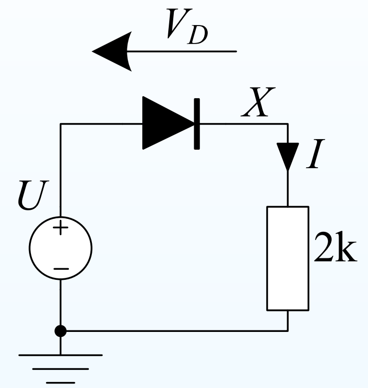

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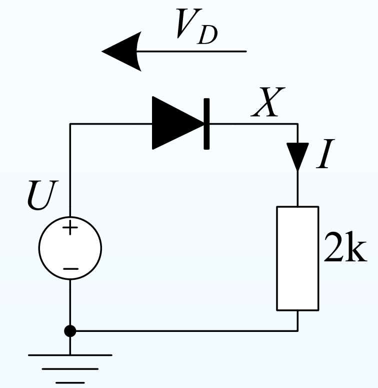
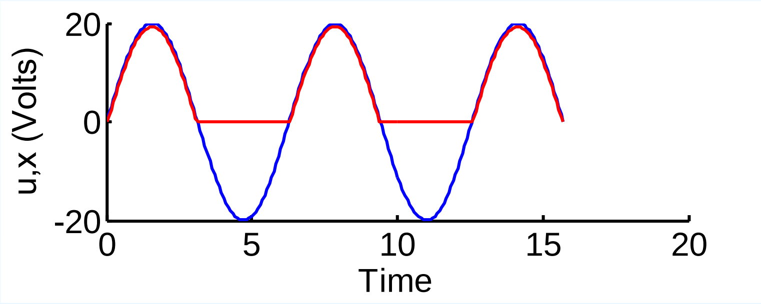


(1) $u(t) = 20 \sin \omega t$

The 0.7 V drop makes little difference.



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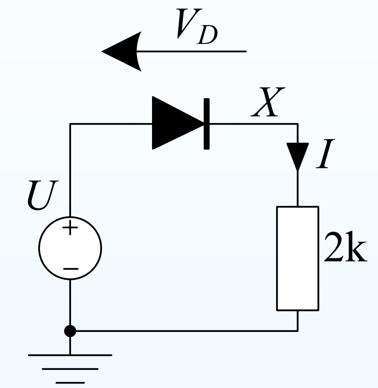

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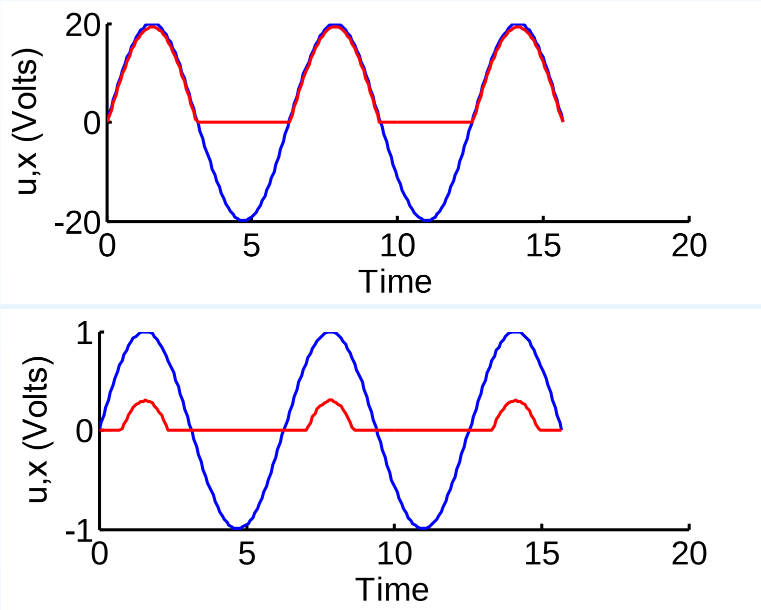
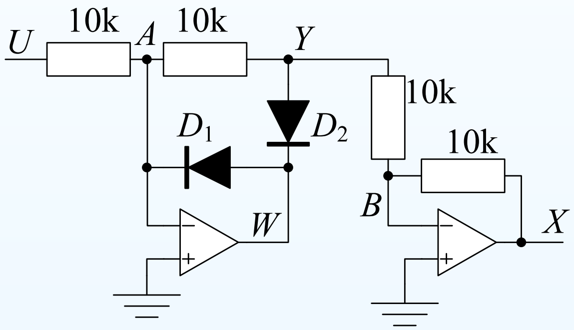


Precision Halfwave Rectifier

Both op-amps have negative feedback, so $A = B = 0$.
Second op-amp is an inverting amplifier so $X = -Y$.



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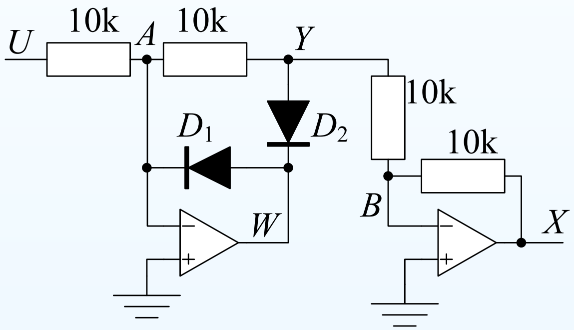

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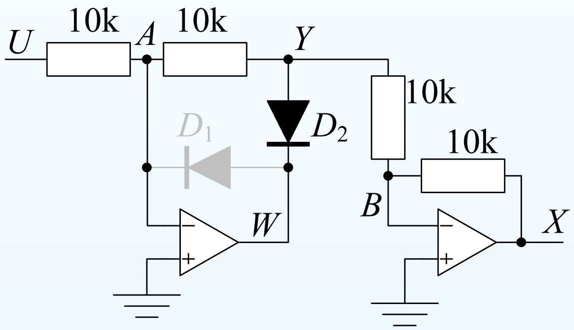

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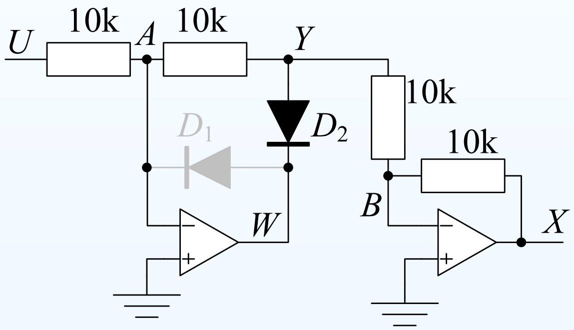

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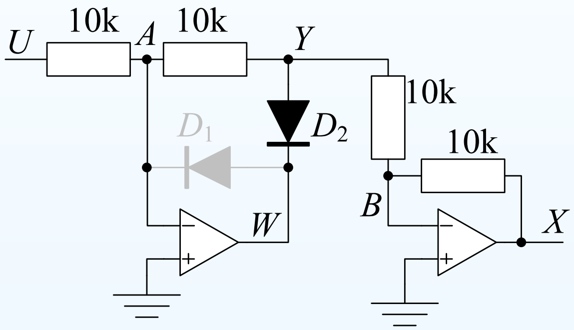

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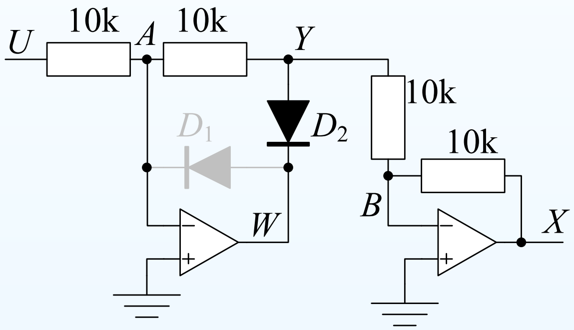

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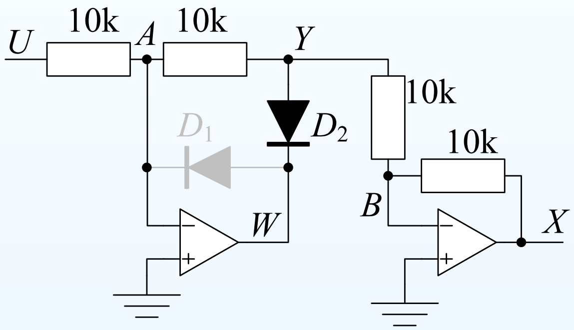

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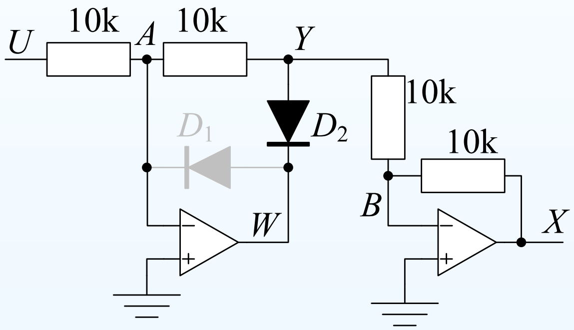

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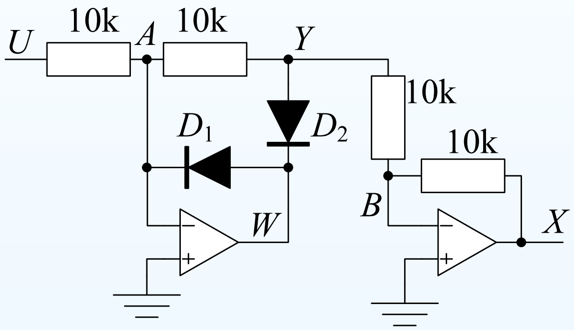

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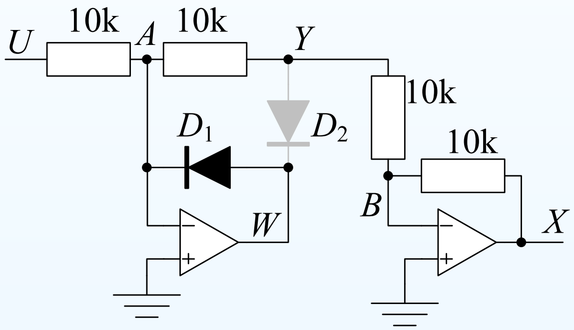

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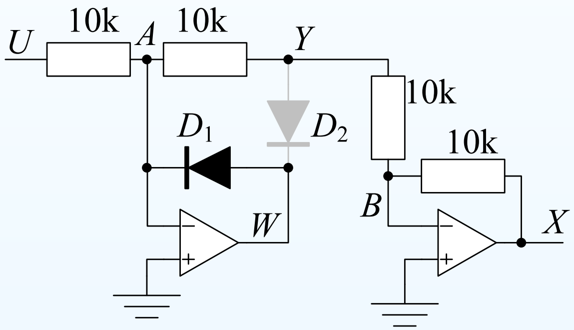

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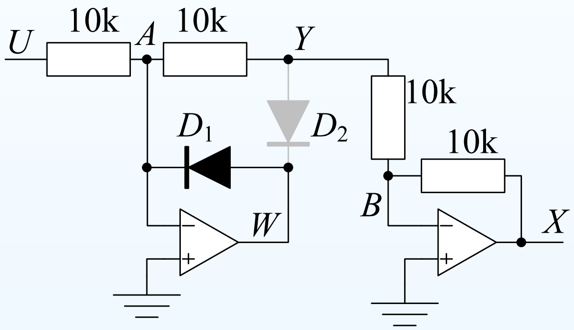

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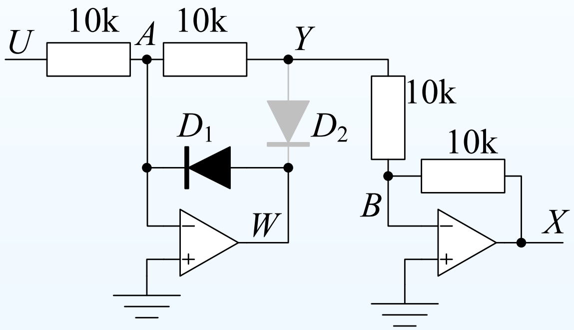

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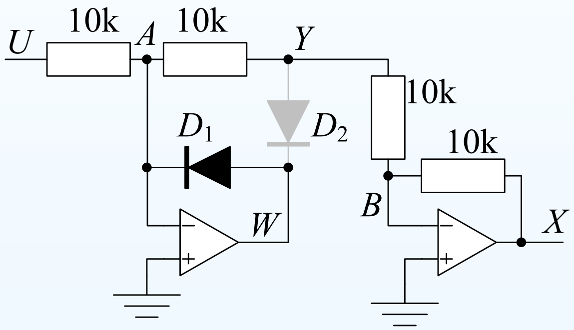

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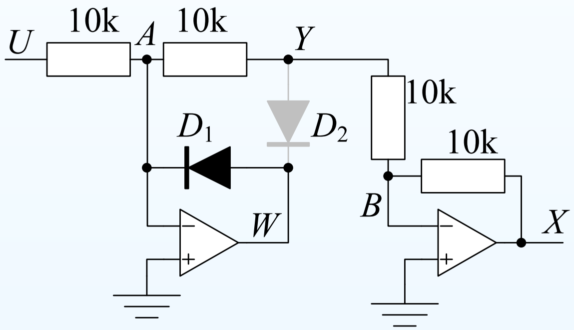

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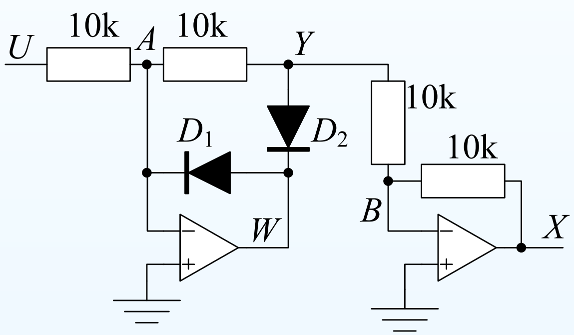

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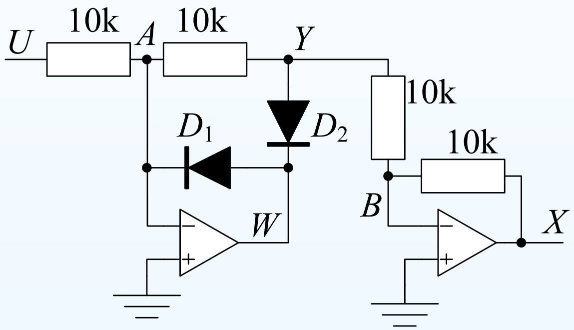

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Putting diodes in a feedback loop allows their voltage drops to be eliminated.

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For further details see Irwin Ch 17.