电子科技大学
University of Electronic Science and Technology of China

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UESTC1008: Microelectronic Systems

PWM & CMOS
Lecture 5

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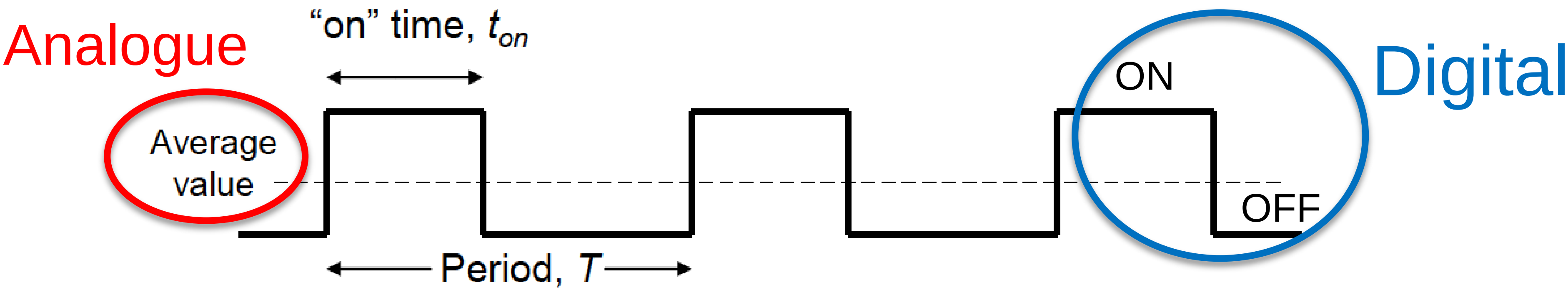
Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM)

Simple method of using rectangular digital waveform to control an analogue variable

Used in a variety of applications, from communications to automatic control



Usually keep period constant, and vary the pulse width, or "on" time

The duty cycle is the proportion of time that the pulse is "on", expressed as a percentage

Duty cycle = (pulse on time) / (pulse period)

Mark to space ratio = (pulse on time) / (pulse off time)

Generating PWM

Could of course, just generate PWM from a digital output by switching it on and off, and changing the time for which the digital signal is “high” or “low”, but that would take up the time and effort of the CPU.

The advantage of handling over responsibility of the PWM signal generation to the specific peripheral in the microcontroller chip, is that the CPU is then available to do other stuff.

This is one of the powerful aspects of a highly functionalised microcontroller – devolving responsibility for things low PWM, D/A and A/D to the peripherals frees up the time of the CPU.

Generating PWM on the mbed

Brute Force

- Use DigitalOut with appropriate wait commands
- Duty cycle not exact and may change during interrupts etc.
- Processor intensive
- Higher power consumption

Smart

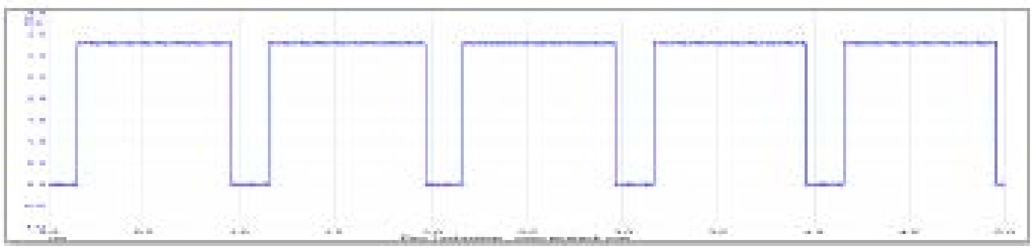
- Or use PwmOut : a dedicated PWM circuit
- Timings are accurate
- Once started, the processor only needs to work if duty or period need changing
- Smaller circuit so lower power consumption

On the mbed

There are several PWM pins on the board e.g., A1, A2, D9, D10 etc.

You can generate various PWM signals…

20% duty cycle



80% duty cycle

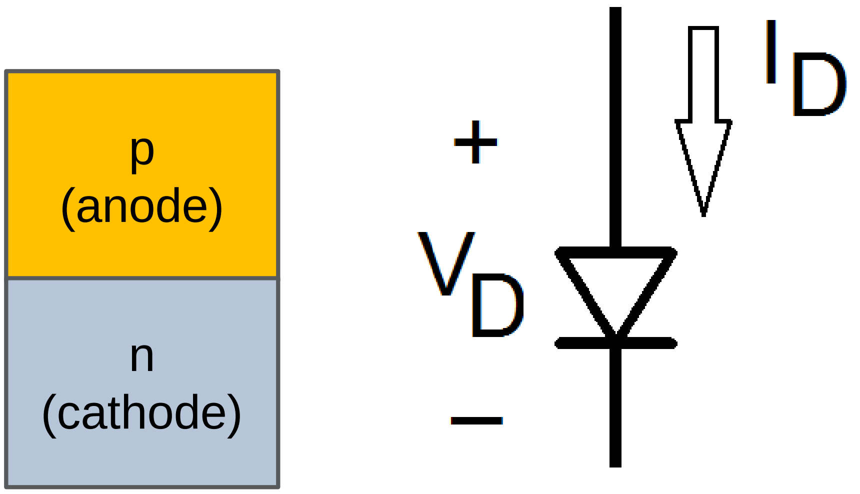
```
PwmOut pwmled(LED1);

pwmled.period(4.2);   // set period to be 4.2 seconds
pwmled.pulsewidth(2);  // set the pulsewidth to be 2 seconds
pwmled.write(0.5);
//can also be simplified to
pwmled=0.5;   //set the duty cycle to 50%
```

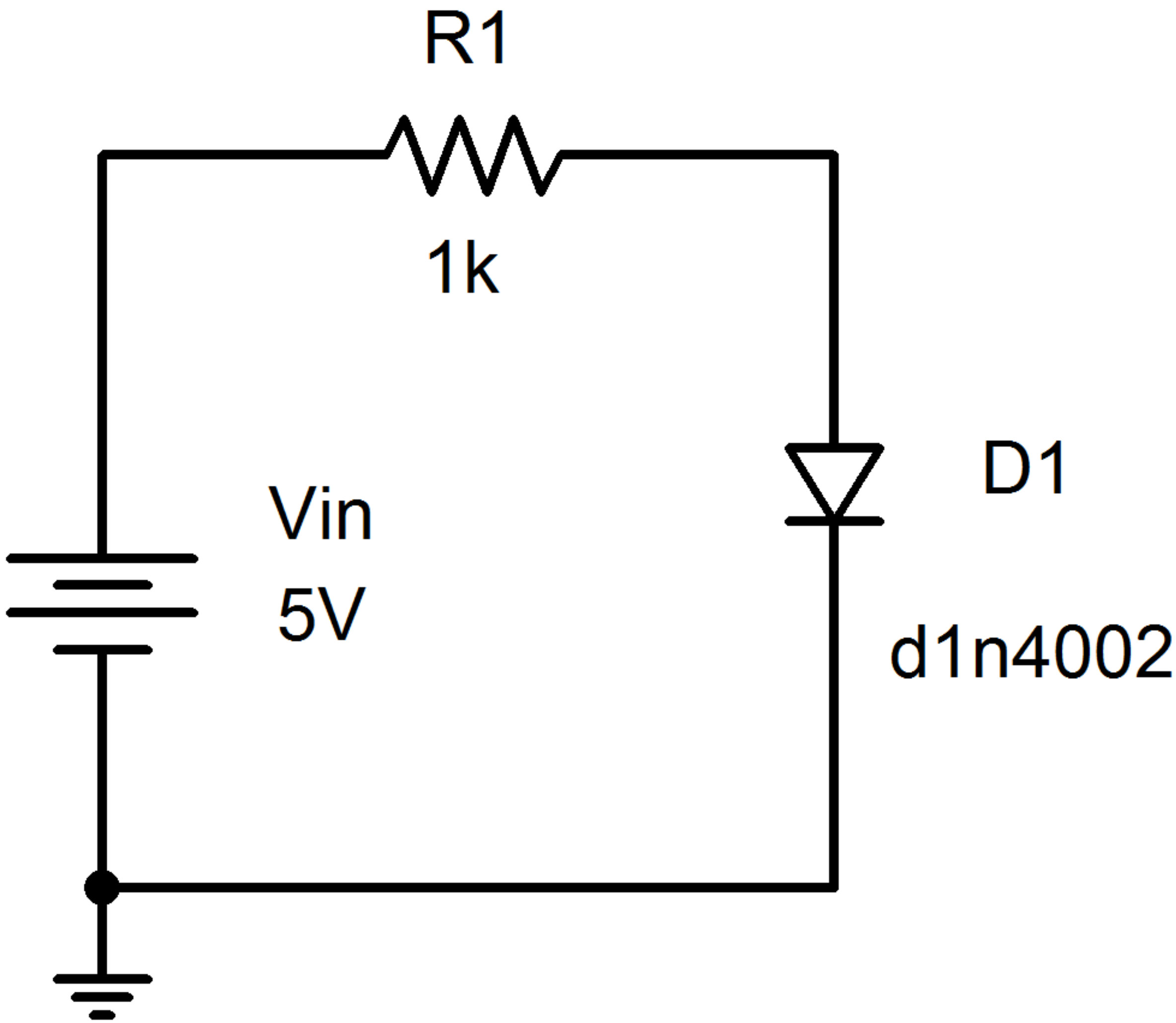
Diode Circuits

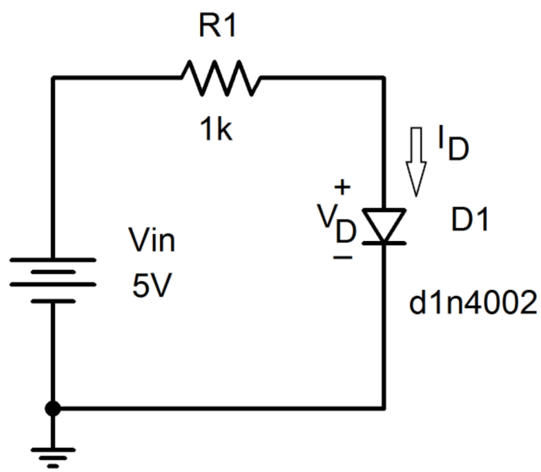
Definition of Diode Current and Voltage

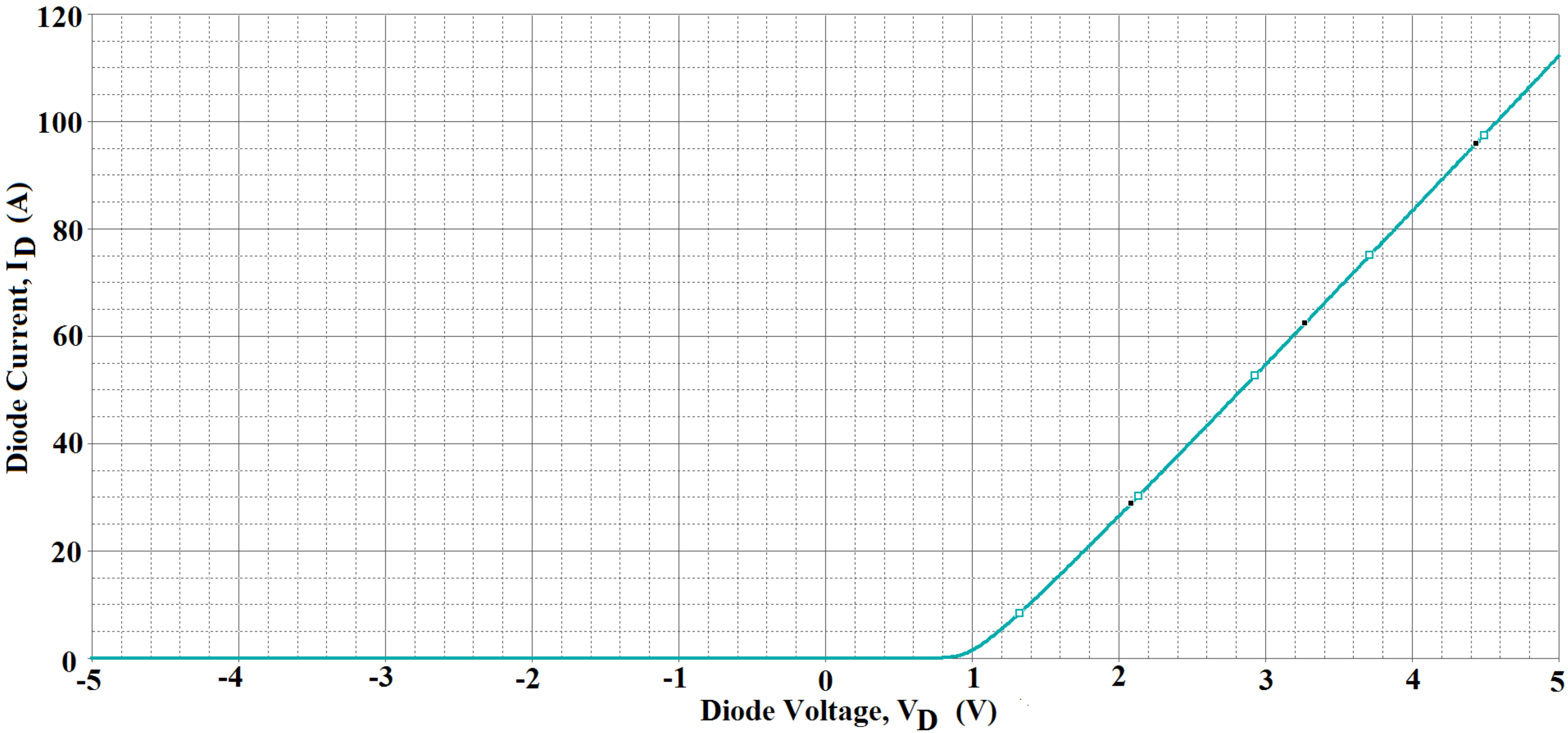
- **Forward Bias**
  - When $I_D > 0mA$ and $V_D > 0V$
- **Reverse Bias**
  - When $I_D < 0mA$ and $V_D < 0V$



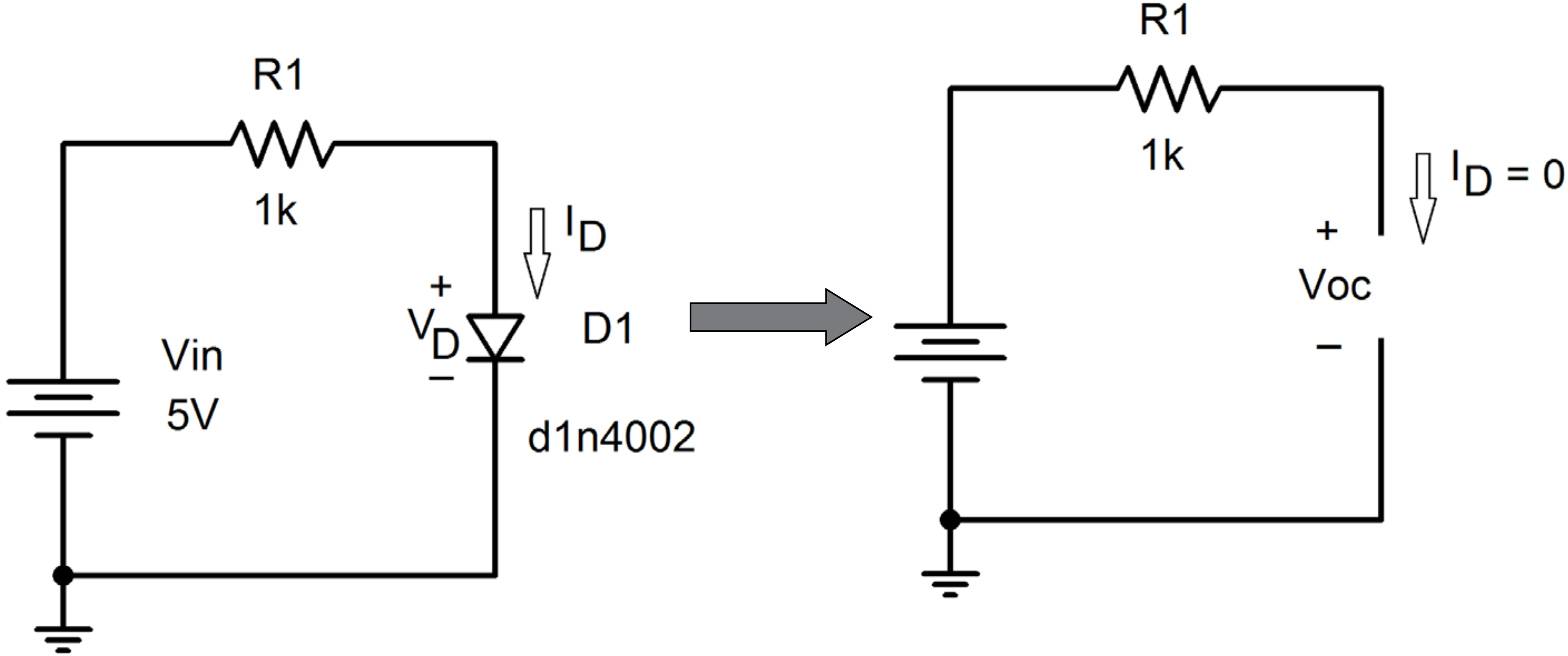
Example




R1
1k
I_D
+
V_D
−
D1
Vin
5V
d1n4002

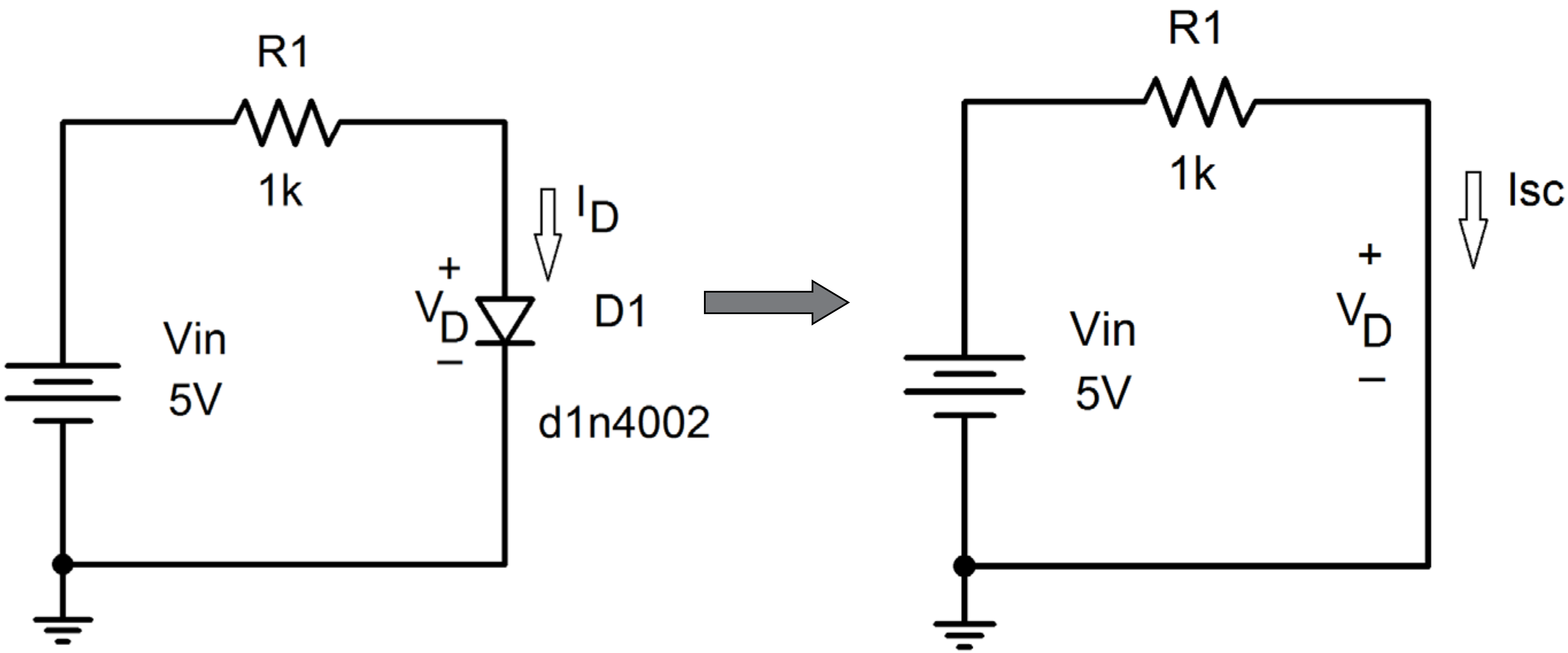

Diode Current, I_D (A)
120
100
80
60
40
20
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Diode Voltage, V_D (V)

Open Circuit Voltage



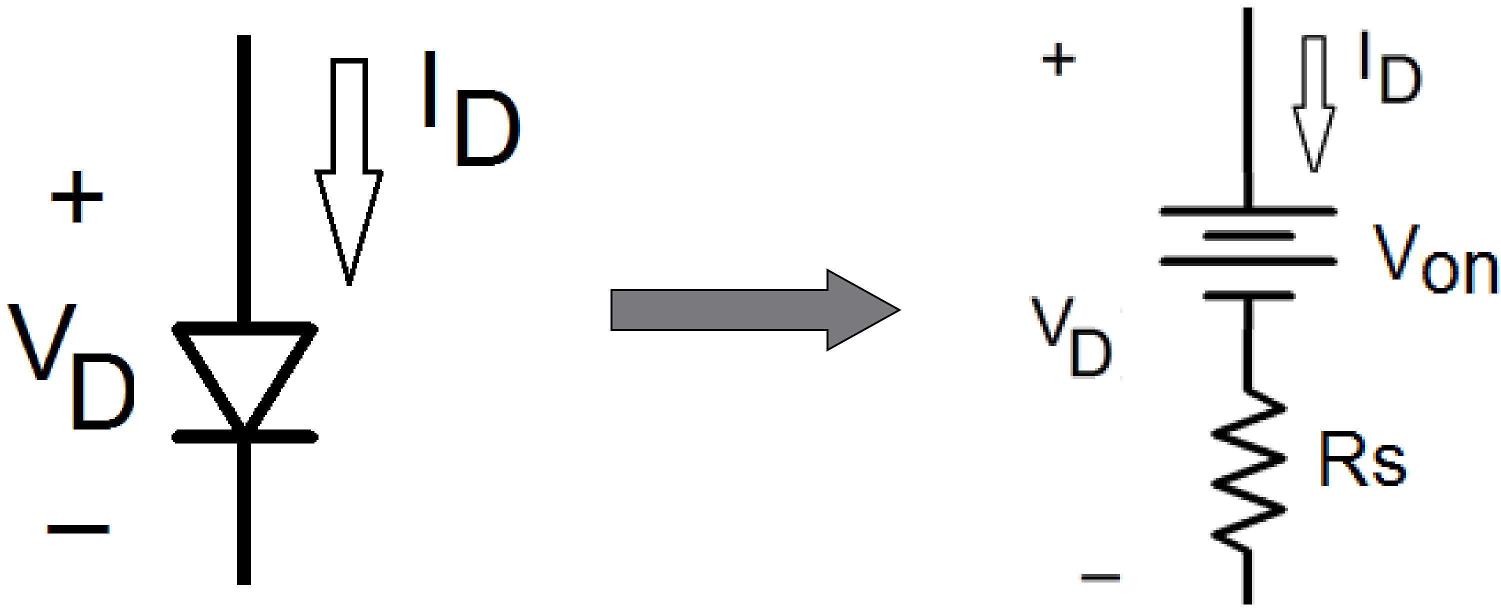
$$V_{OC} = 5V$$

Short Circuit Current



$$I_{SC} = \frac{5V}{1k\Omega} = 5mA$$

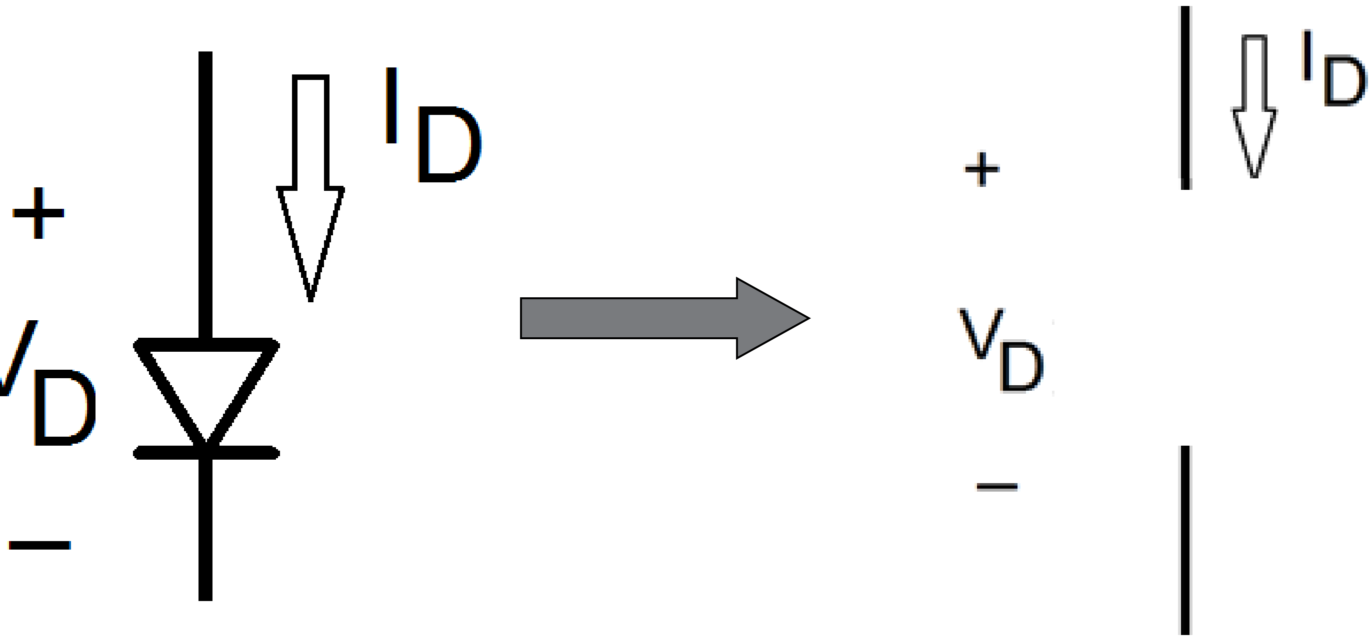
"ON" Model



$V_D \geq V_{on}$

$I_D \geq 0$ mA

“OFF” Model



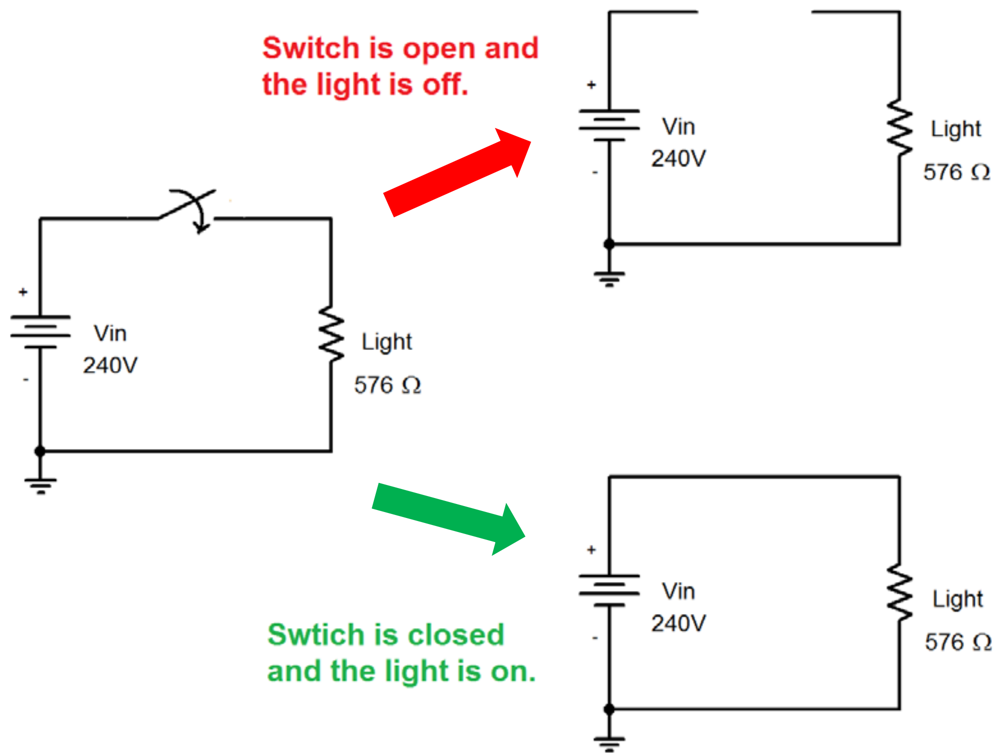
$V_D < V_{on}$

$I_D = 0$ mA

Operation of a Switch

Typically, switches are used to connect and disconnect parts of one circuit with other parts of a circuit.

Here is a schematic for a circuit where the switch is used to connect a light bulb to the dc power supply. The switch used in this case is a single pole, single throw (SPST).



Questions:

What is the power dissipated by the Light?

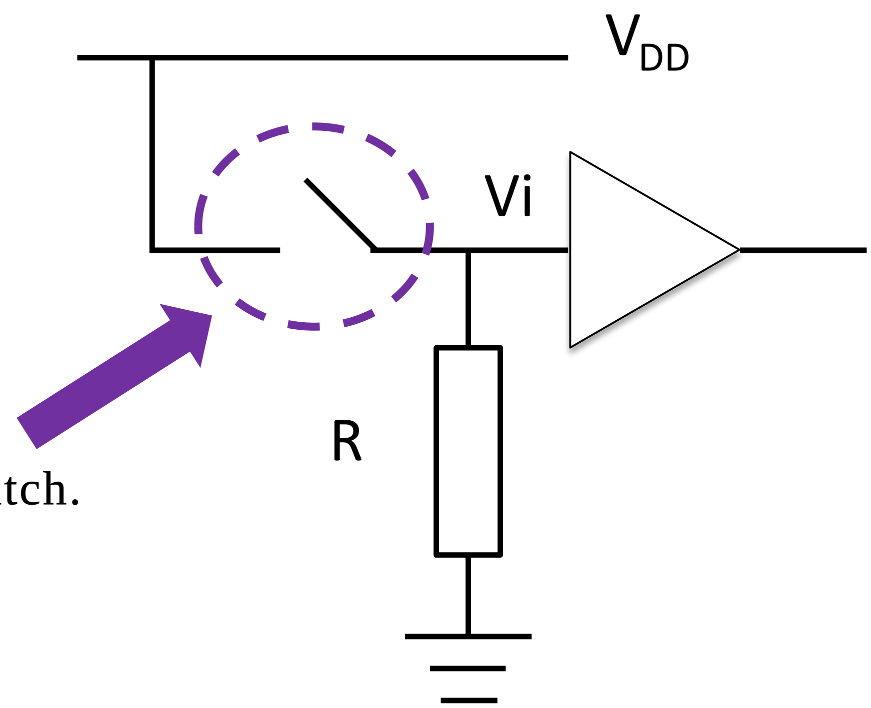
Why would putting the switch between the Light and ground be dangerous when changing the light bulb?

MOSFET
Metal Oxide Semiconductor Field Effect Transistor

- As switches

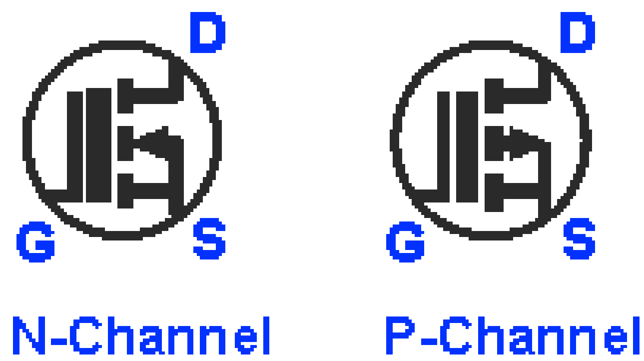
mbed

- When you assign a value to a pin on the mbed, it causes a voltage to be applied to the MOSFET switch.



This is a MOSFET switch.

Metal Oxide Semiconductor Field Effect Transistor : MOSFET



- n or p channel
- Enhancement or depletion mode
- Typical is the n channel enhancement FET
  - n type source and drain, p type channel
  - +ve voltage on gate relative to source causes negative charge in the channel and causes conduction
  - Gate isolated from conduction channel by dielectric – just uses charge
  - Very low current to turn on ideal for scaling in ICs
- Very low on resistance
- Very high off resistance
- Only uses energy to charge/discharge the gate

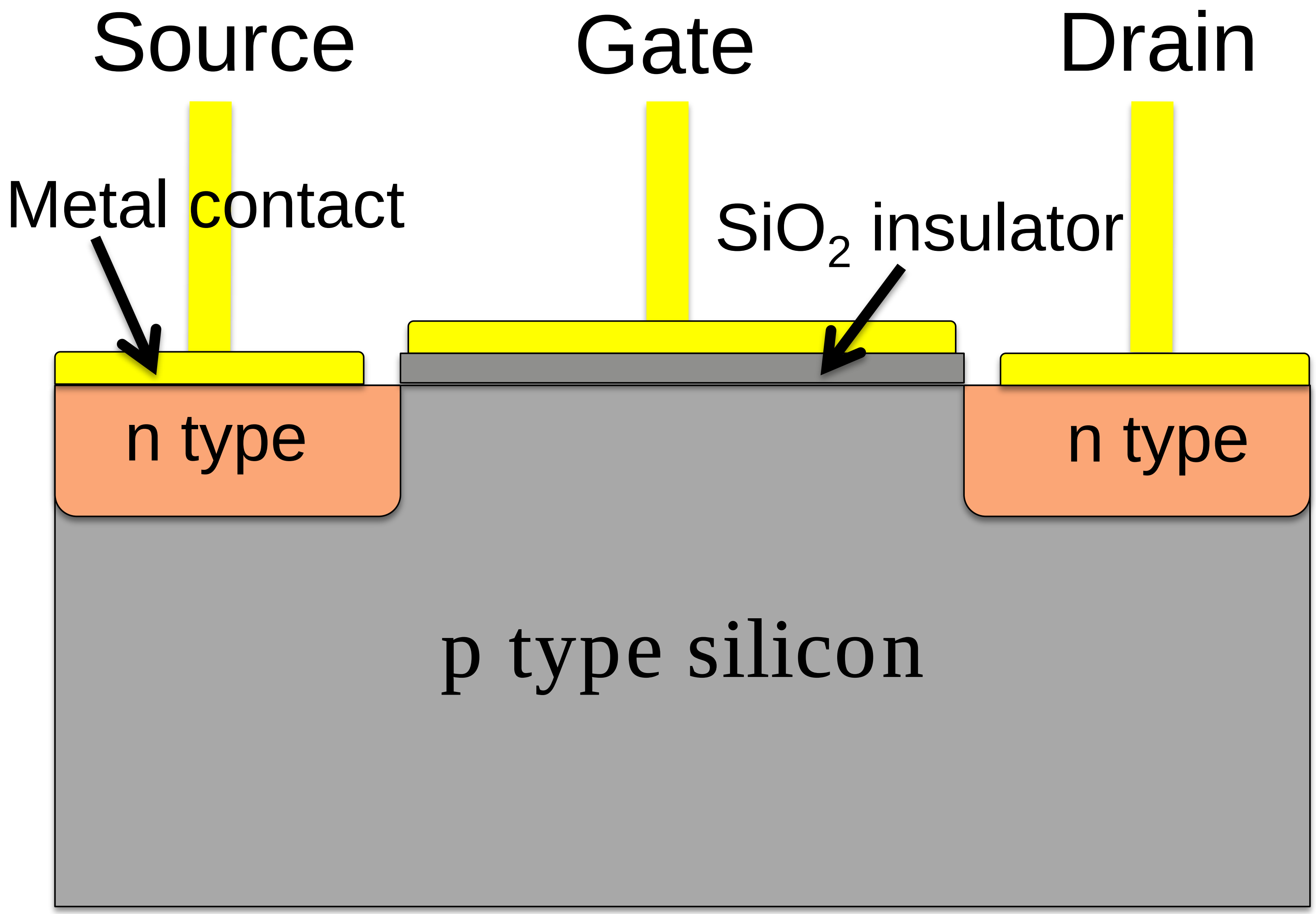
Enhancement Mode and Depletion Mode Switches

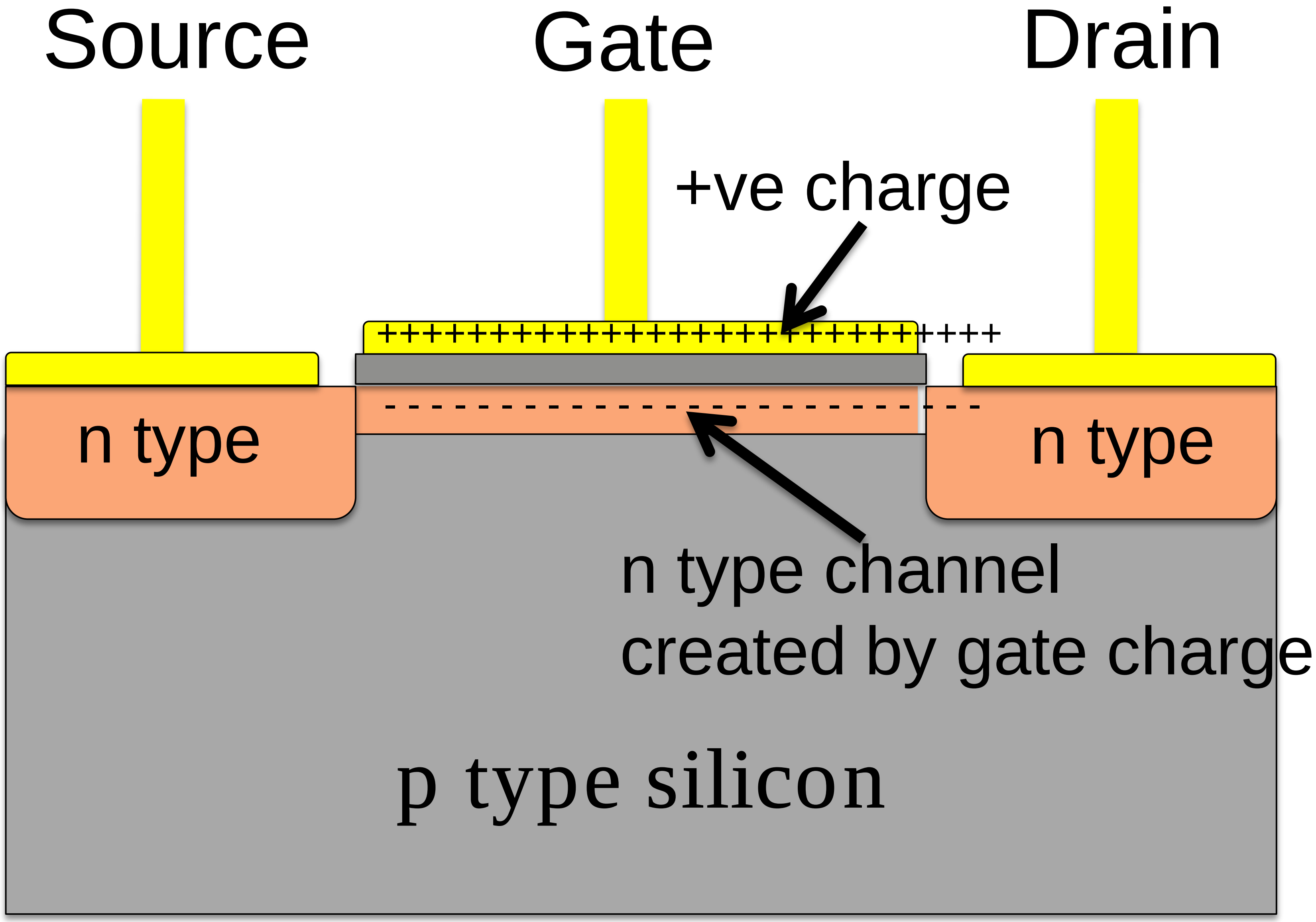
NMOS Enhancement Mode

- Normally OFF
  - **You have to apply a voltage to make V_{GS} more positive than the threshold voltage for an NMOSFET to turn it on.**

NMOS Depletion Mode

- Normally ON
  - **You have to apply a voltage to make V_{GS} more negative than the threshold voltage for an NMOSFET to turn it off.**


Source
Gate
Drain
Metal contact
SiO2 insulator
n type
n type
p type silicon


Source
Gate
Drain
+ve charge
++++++++++++++++++++++++++++++++++
n type
- -
n type
n type channel
created by gate charge
p type silicon

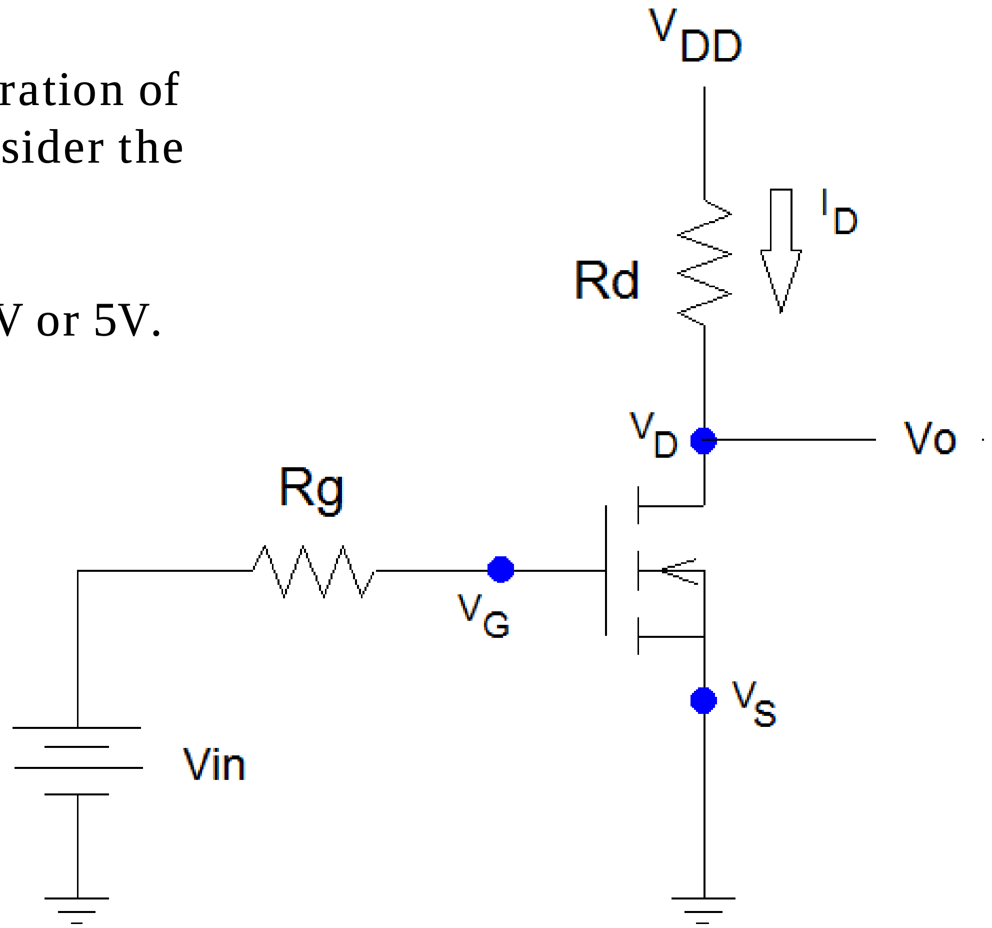
Types of Switches

- Two common ways to connect or disconnect one part of a circuit with another:
  - **Mechanical – physical movement is require to make or break the connection.**
    - **Debounce circuits may be needed if the switch makes intermittent contact as its position is changed.**
  - **Electrical – the conductivity of a component is changed from insulating to conducting and back again (visa versa).**
    - **Useful when switching is done remotely.**
    - **They are required in hazardous locations where sparks can ignite fires.**
    - **The lifetime and reliability of an electrical switch is typically better than a mechanical switch.**
    - **Usually their size is smaller than mechanical switch to allow the same amount of current to flow through the switch.**

NMOS Inverter

One way to analyse the operation of an NMOS inverter is to consider the MOSFET to be a switch.

Assume that Vin is either 0V or 5V.

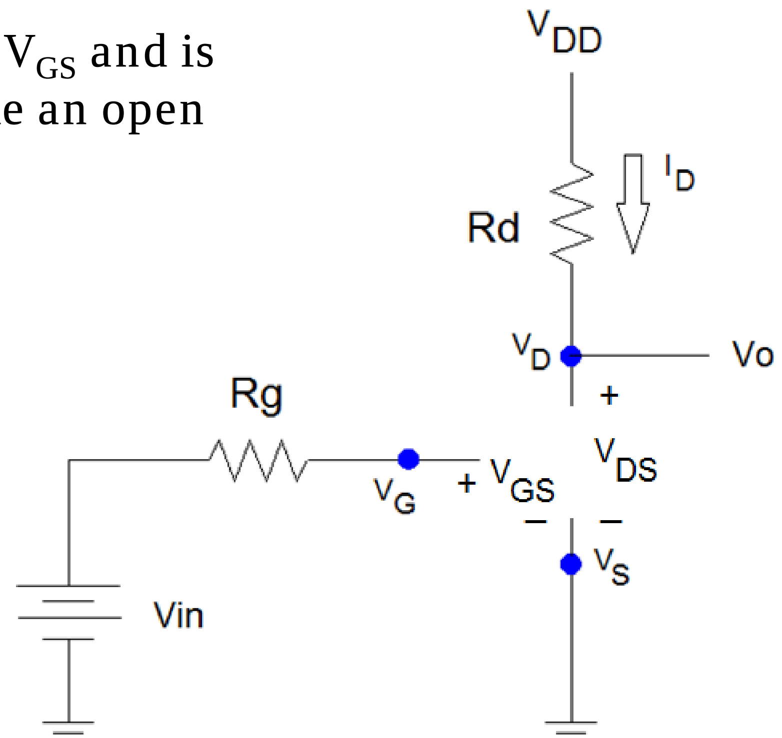


Cut-off Region

When Vin = 0V, which is equal to V_{GS} and is less than V_T, the MOSFET acts like an open circuit.

No current flows through R_D.

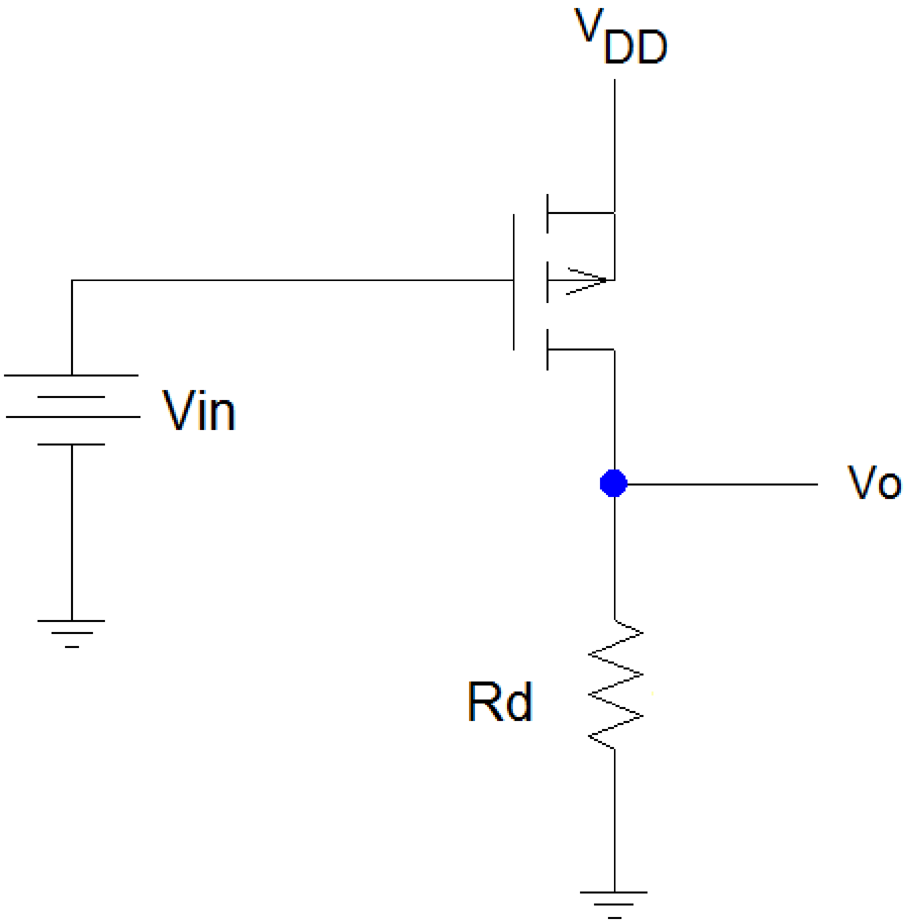
The output voltage Vo = V_{DD}.



Important Input Voltages

Vin	NMOS	PMOS
High	short	open
Low	open	shot

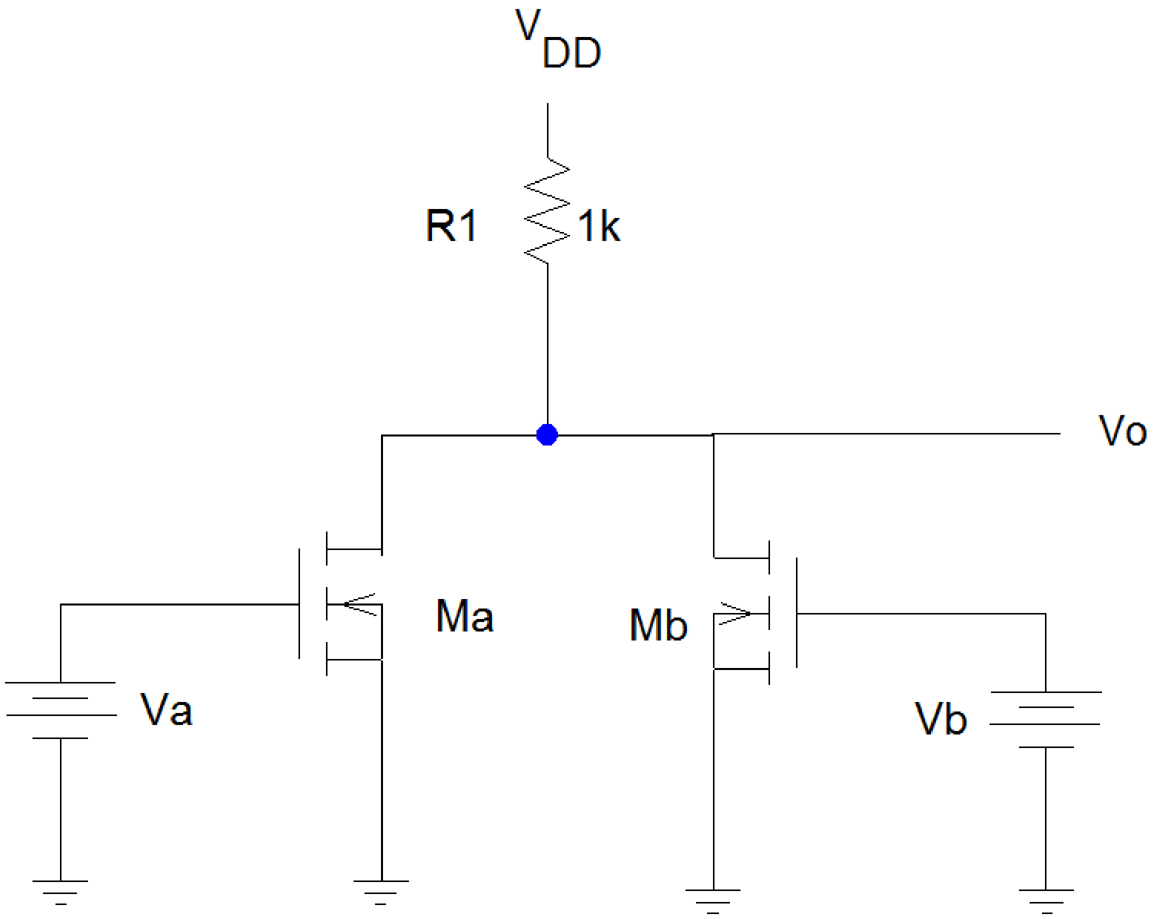
Enhancement Mode PMOS Switch

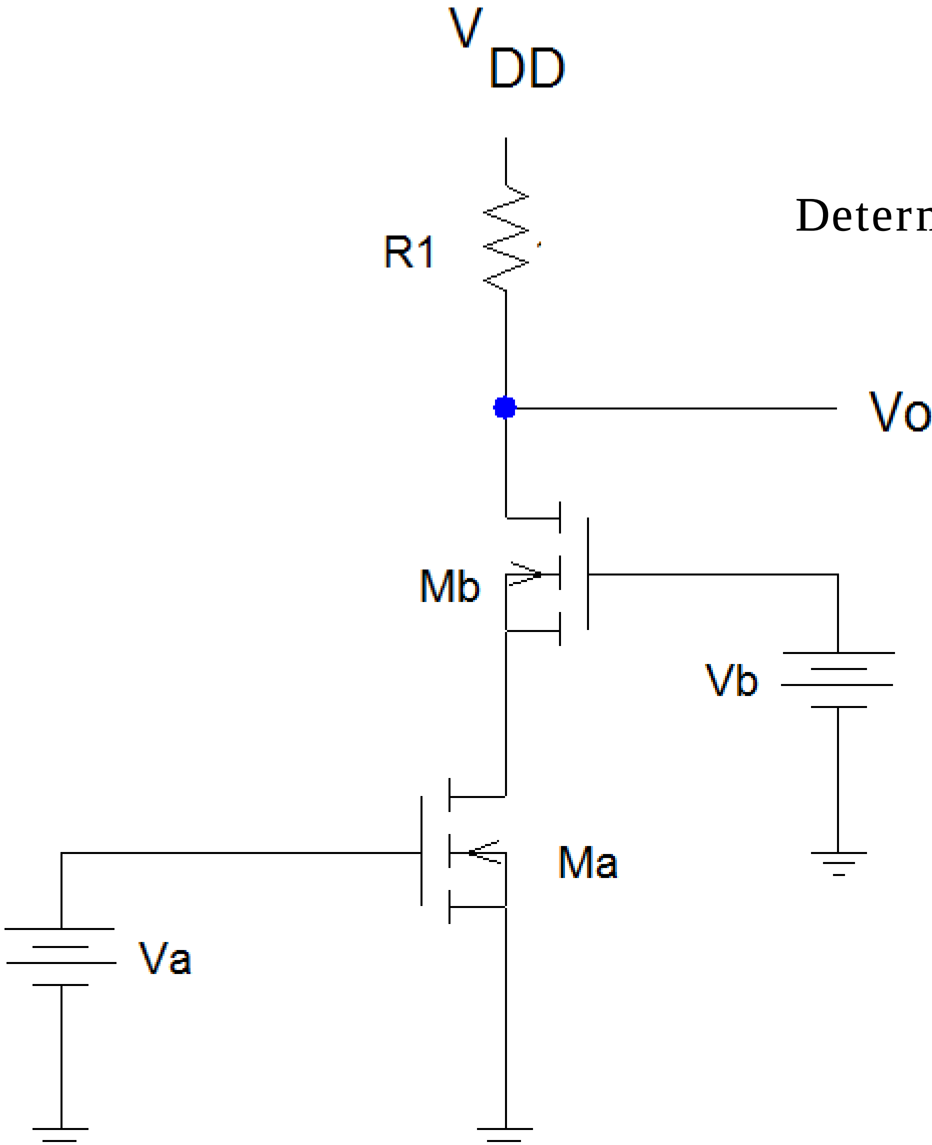


Does the switch allow current to flow when V_{DD} is 0V or 5V?

NMOS Logic

Determine the truth table for this circuit.





Determine the truth table for this circuit.

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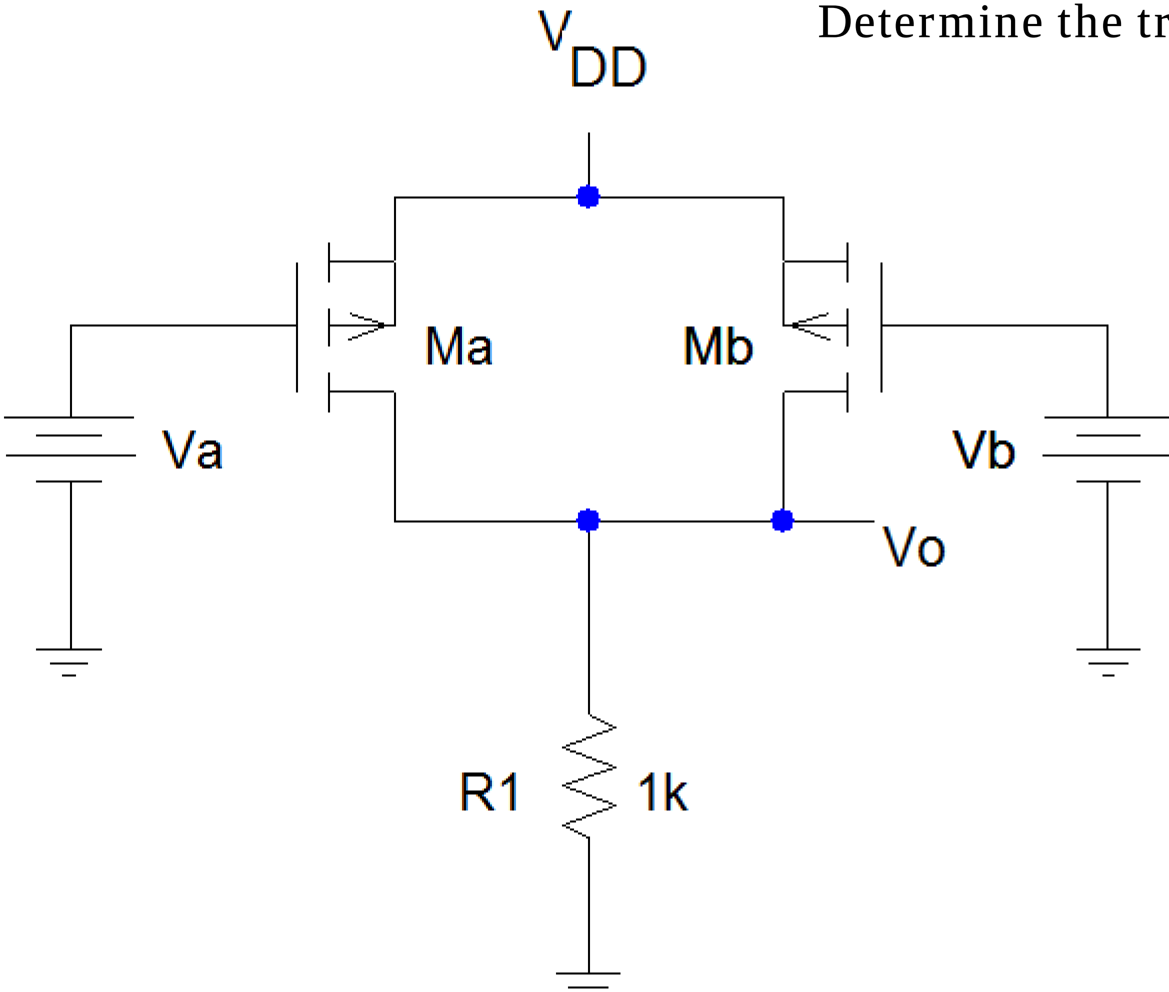
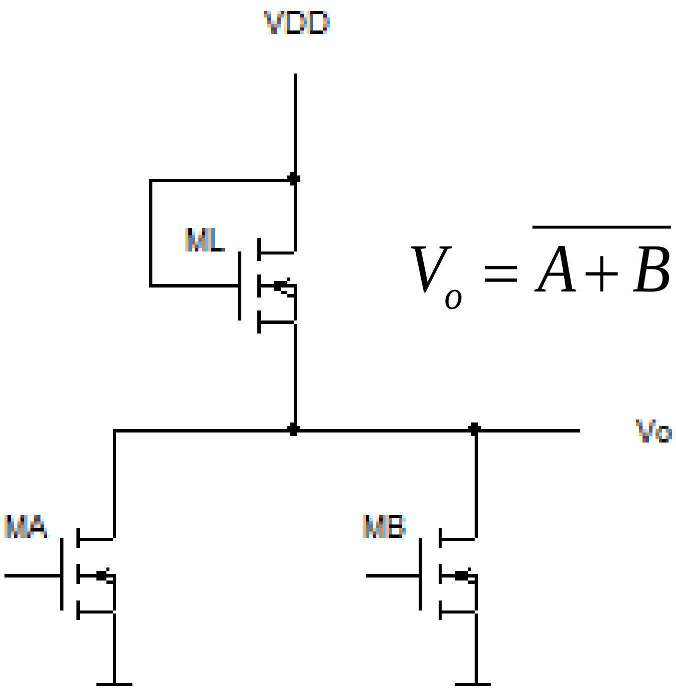


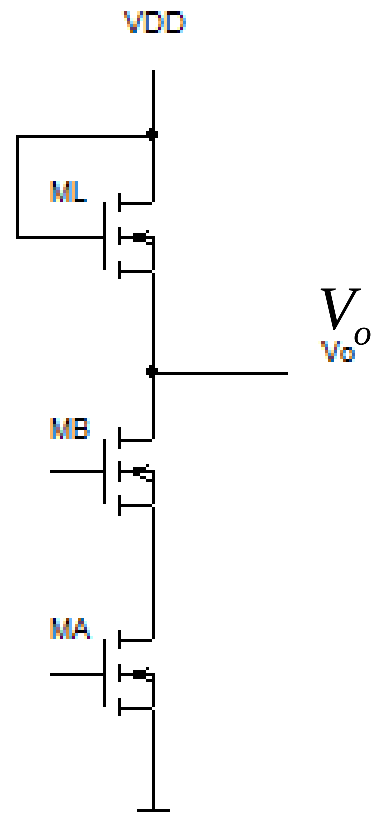
Logic Functions using NMOS

- When either MA or MB is turned on, V_o is pulled down towards ground.
- When both MA and MB are off, ML pulls V_o up to V_{DD}.



$$V_o = \overline{A+B}$$

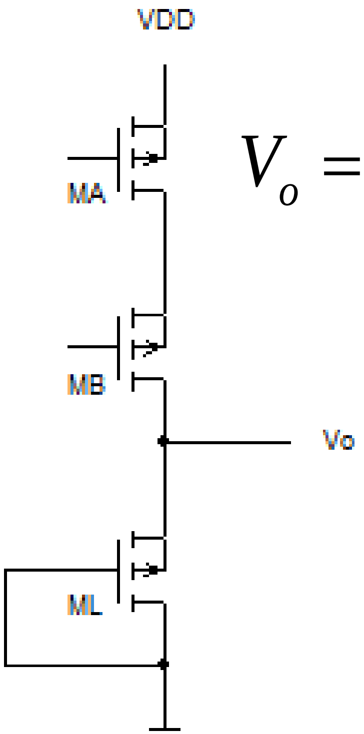
- When both MA and MB are turned on, V_o is pulled down towards ground.
- When either MA and MB or off, ML pulls V_o up to V_{DD}.



$$V_o = \overline{A \cdot B}$$

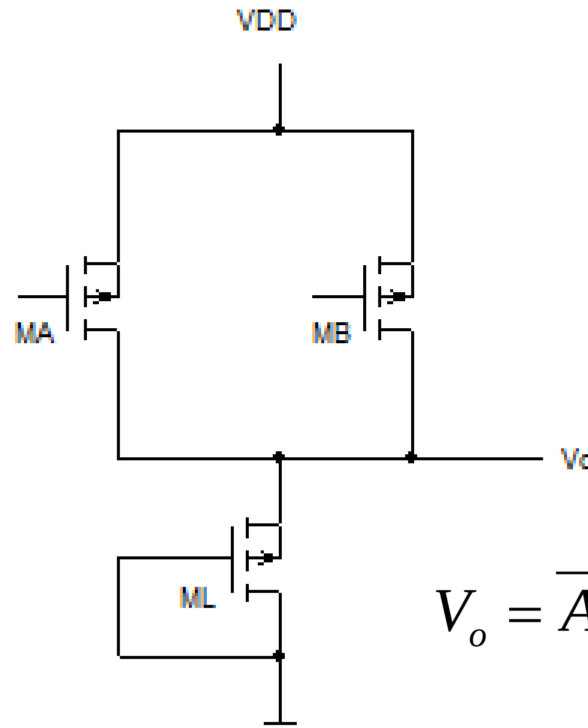
Logic Functions using PMOS

- When both MA and MB is turned on, V_o is pulled up to V_{DD}.
- When either MA or MB are off, ML pulls V_o down towards 0V.



$$V_o = \overline{A + B} = \overline{A} \cdot \overline{B}$$

- When either MA or MB is turned on, V_o is pulled up to V_{DD}.
- When both MA and MB are off, ML pulls V_o down towards 0V.



$$V_o = \overline{A \cdot B} = \overline{A} + \overline{B}$$