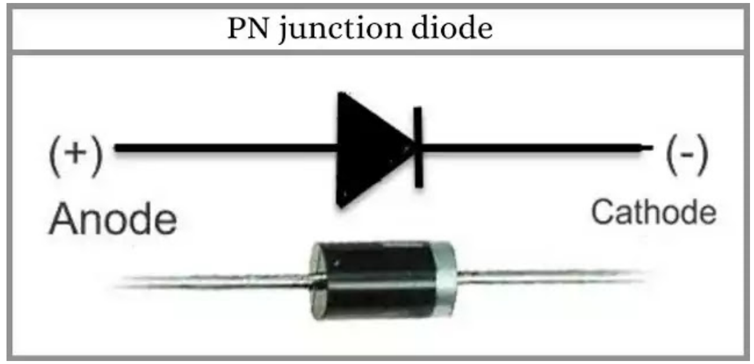
電子電工學
Lecture 14

Change Behaviour

Chapter 12



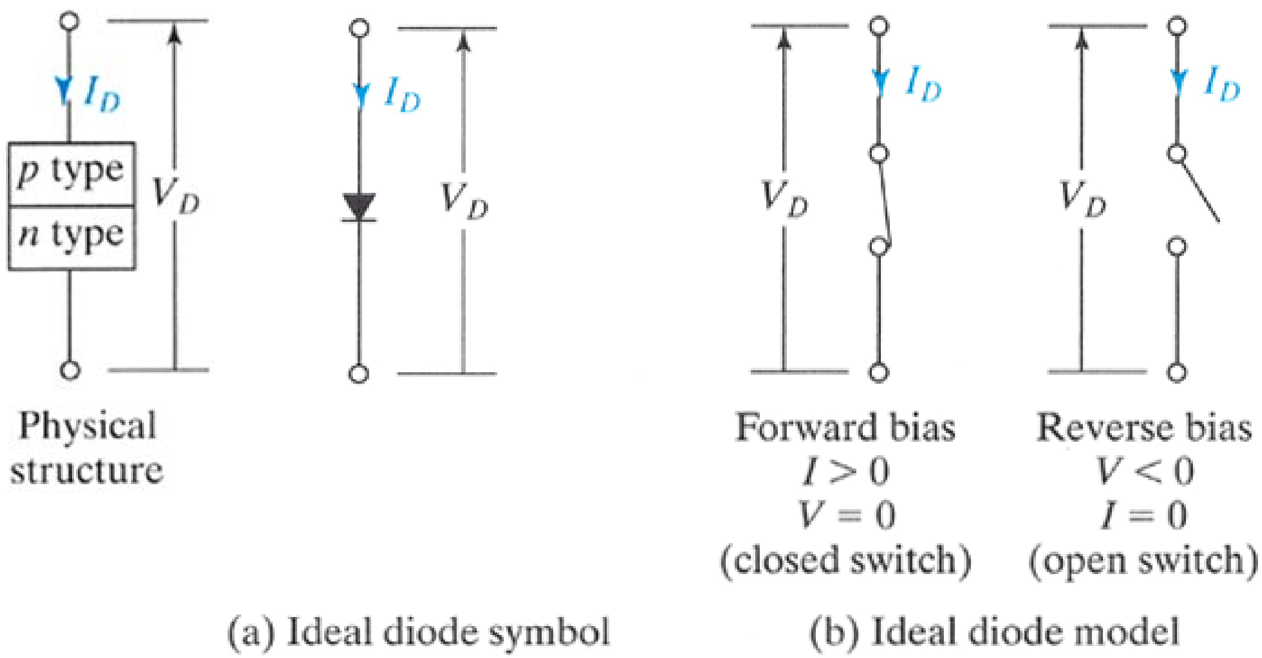
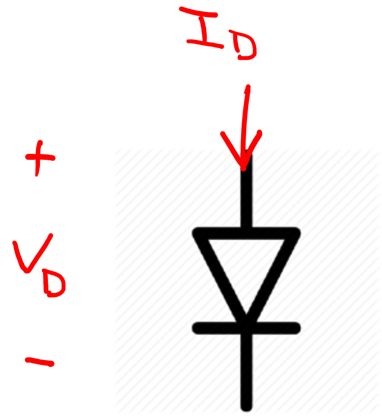


FIGURE 10.17 Ideal diode symbol and its switch circuit model.

Idea diode



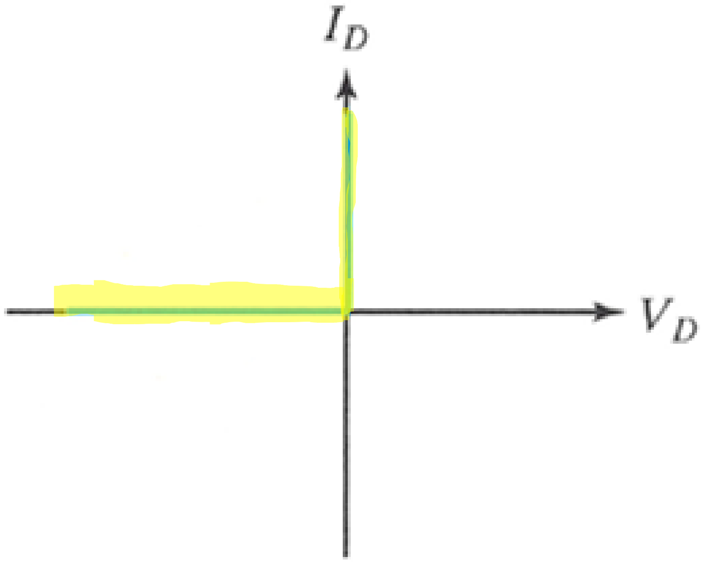
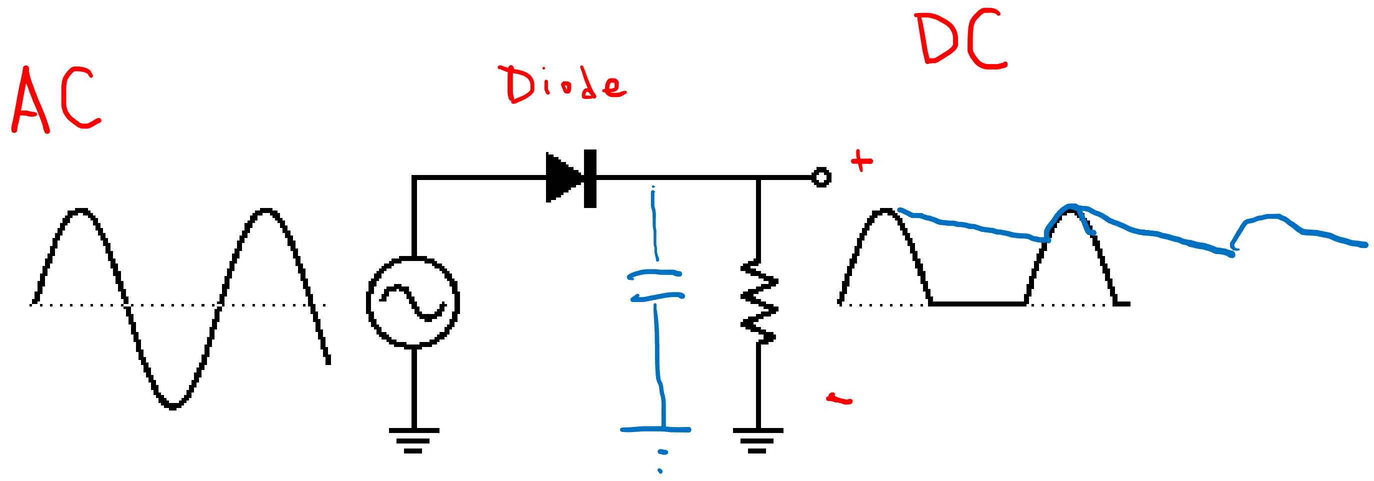


FIGURE 10.16 Plot of current through diode, I_D, versus voltage across diode, V_D, for an "ideal" diode.

Application: Rectifier

整流



Diode characteristic

Real-world diode (Not ideal)

0V

Stablizer
Regulator

0.7 V voltage drop

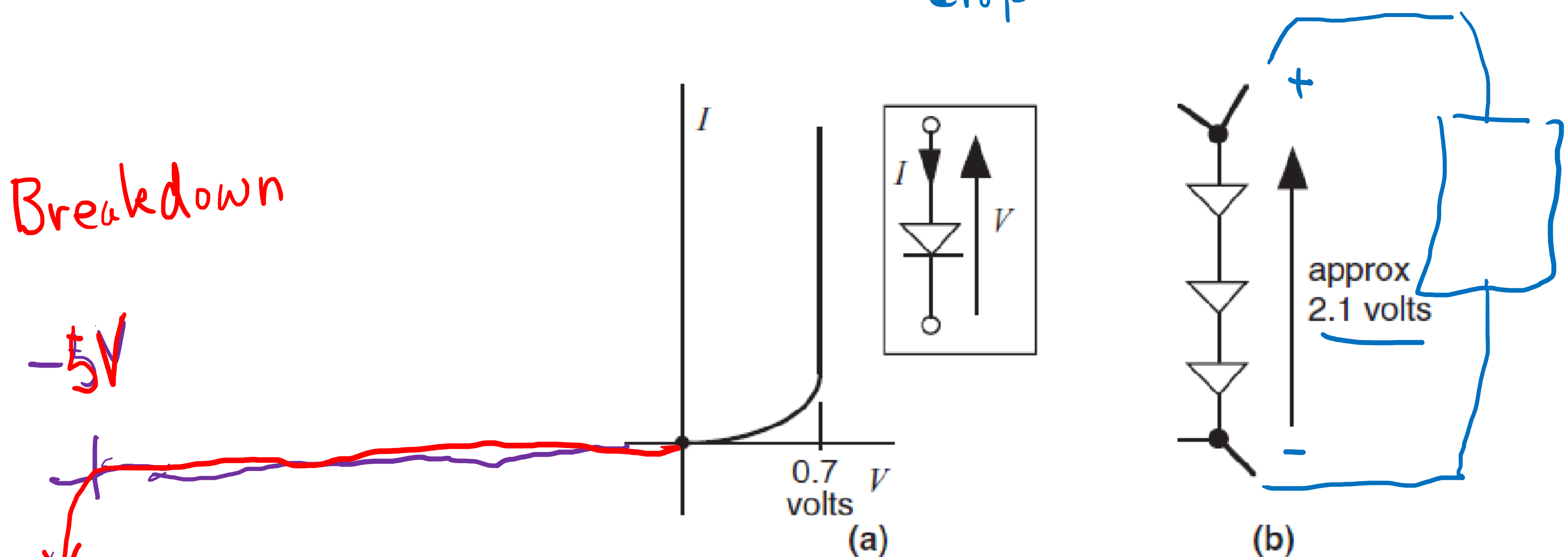


Figure 12.1 A diode characteristic, and the use of diodes to establish a fixed voltage within a circuit

Zener diode characteristic

Recoverable breakdown

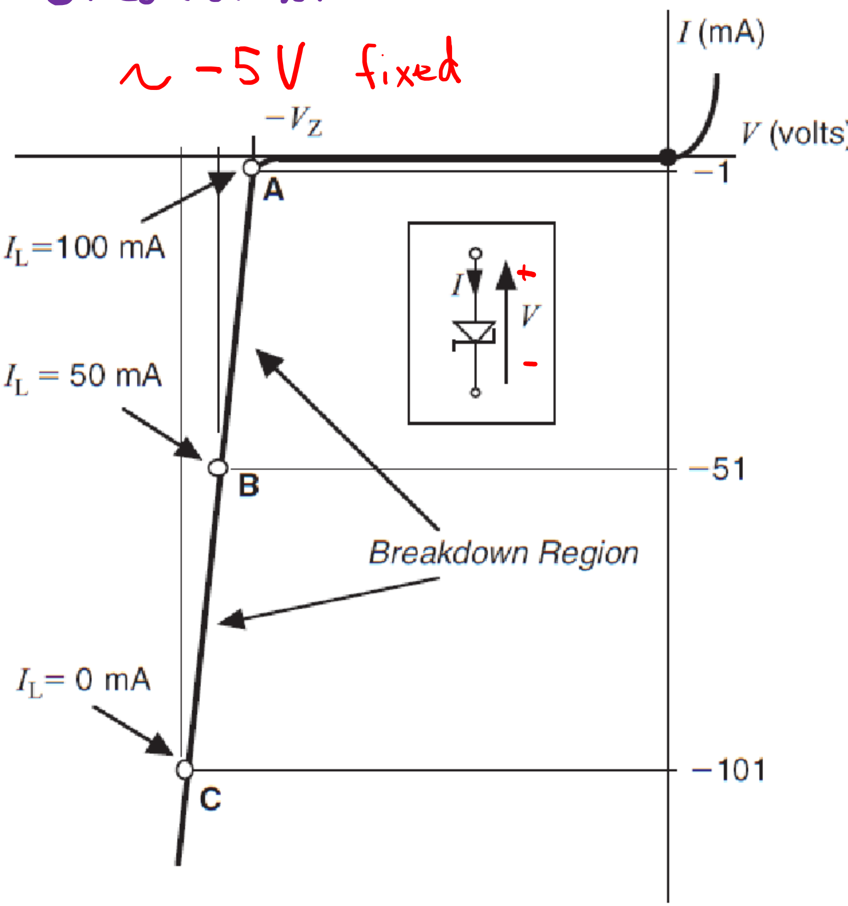


Figure 12.2 The voltage~current characteristic of a Zener diode. Operation in the breakdown region is nondestructive

Stabilizer

Purpose:
To provide stable voltage to load

~ fixed V   R variable

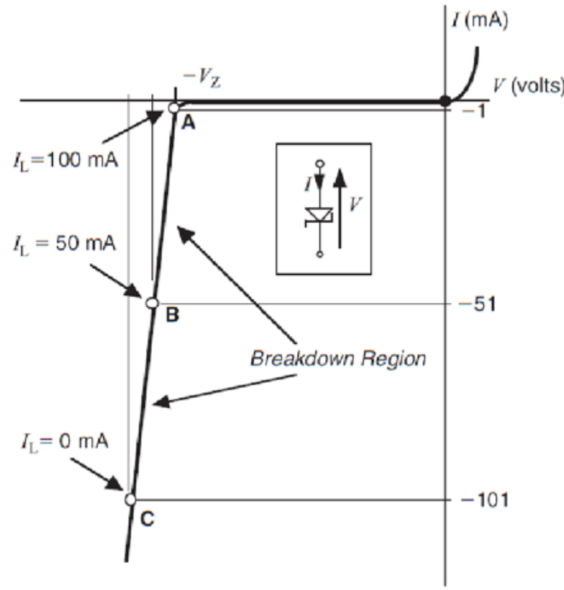


Figure 12.2 The voltage~current characteristic of a Zener diode. Operation in the breakdown region is nondestructive

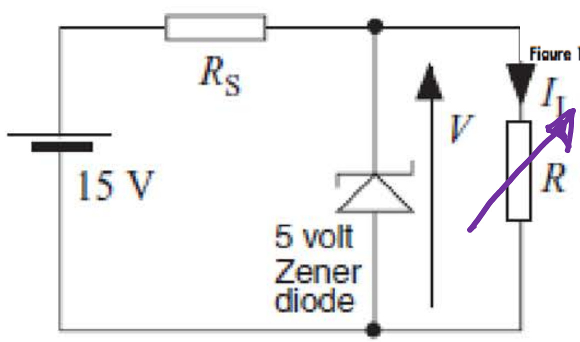


Figure 12.3 A circuit in which the Zener diode helps to maintain the voltage V at approximately 5 V

Stabilizer

Operating point A

Zener diode just turned-on

Least current $I_Z = 1\ mA$

$\Rightarrow I = I_L + I_Z \cong 101\ mA$

Design $R_s = \dfrac{15-5\ (V)}{101\ (mA)} = 99\ \Omega$

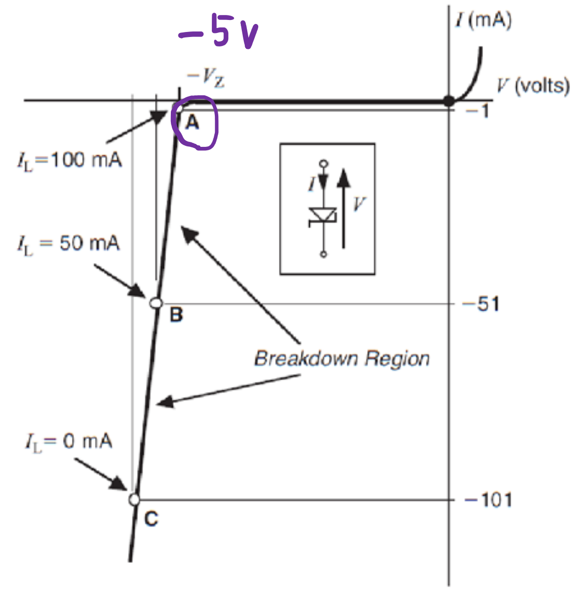
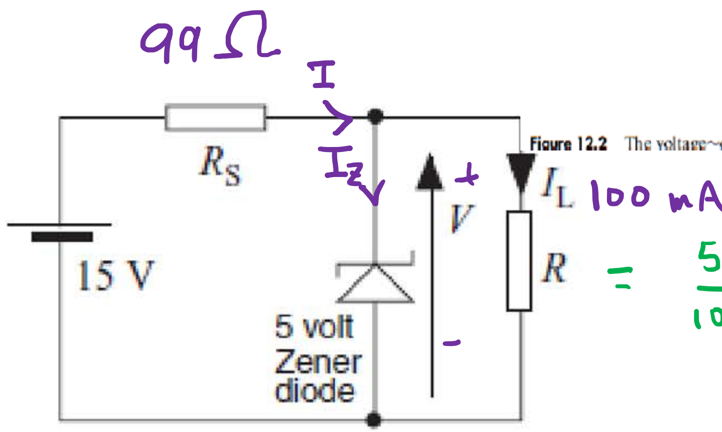


Figure 12.2 The voltage–current characteristic of a Zener diode. Operation in the breakdown region is nondestructive



$= \dfrac{5\ V}{100\ mA} = 50\ \Omega$

Figure 12.3 A circuit in which the Zener diode helps to maintain the voltage V at approximately 5 V

Stabilizer

Operating point B $\quad R_s = 99$ fixed

Load extract $50\,mA = I_L$

$\left(R \hat{=} \frac{5V}{50\,mA} = 100\,\Omega \right)$

$I = \frac{15-5}{99} = 101\,mA$

$\Rightarrow I_Z = I - I_L = 51\,mA$

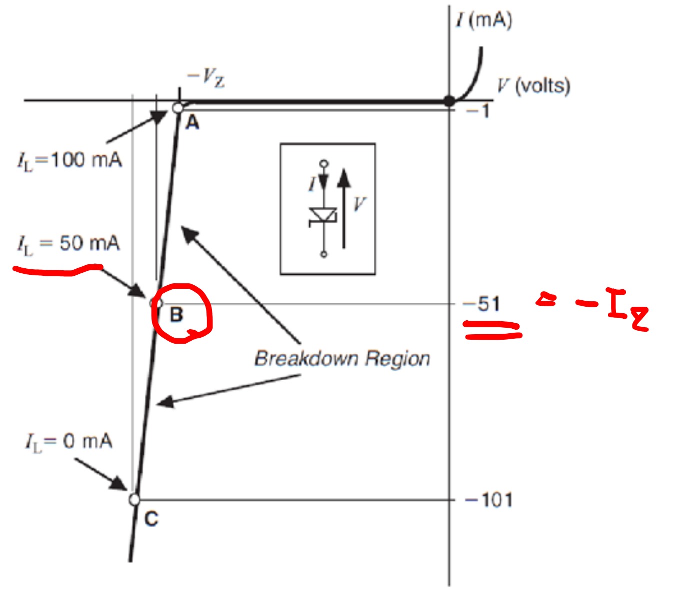


Figure 12.2 The voltage–current characteristic of a Zener diode. Operation in the breakdown region is nondestructive

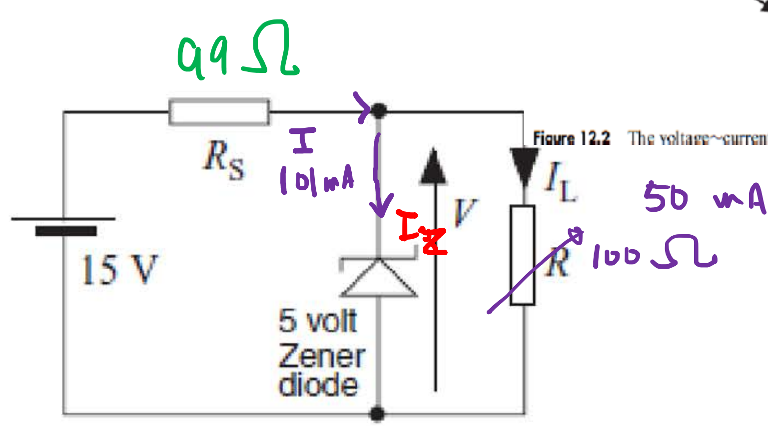


Figure 12.3 A circuit in which the Zener diode helps to maintain the voltage V at approximately 5 V

Stabilizer

Operating point C

$R \to \infty$

Load extracts 0 mA

$V = 5\ V$

$I = 101\ mA$

$\Rightarrow I_Z = 101\ mA$

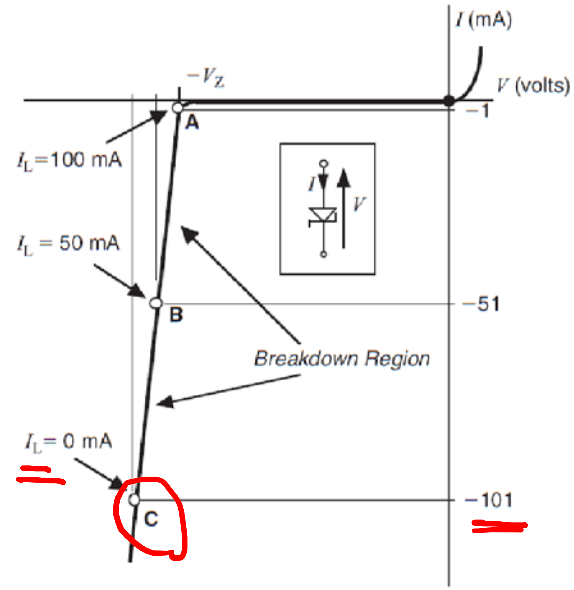


Figure 12.2 The voltage–current characteristic of a Zener diode. Operation in the breakdown region is nondestructive

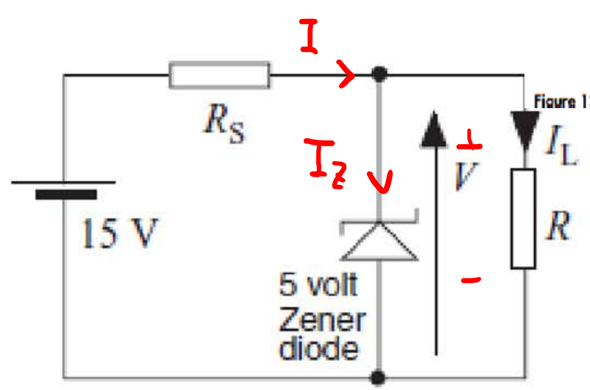


Figure 12.3 A circuit in which the Zener diode helps to maintain the voltage V at approximately 5 V

Stabilizer summary

1. Maintain essentially a constant voltage

Ideal Zener diode $V = \text{const}$

2. Real-world Zener diode: a small change in V $\rightarrow V + \Delta V$

$I_L \longrightarrow I_L + \Delta I$

$V \longrightarrow V + \Delta V$

$\Delta I \ ? \rightarrow \Delta V$

Change Analysis

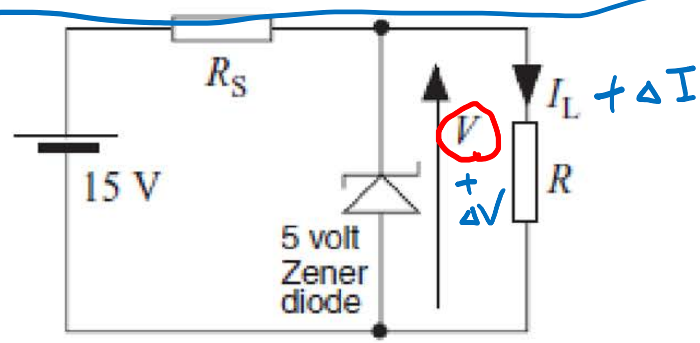


Figure 12.3 A circuit in which the Zener diode helps to maintain the voltage V at approximately 5 V

Connections

Node X

$I_i \rightarrow I_i + \Delta I_i$

by KCL at X

$$\begin{cases} I_1 + I_2 + I_3 = 0 \\ (I_1 + \Delta I_1) + (I_2 + \Delta I_2) + (I_3 + \Delta I_3) = 0 \end{cases}$$

$$\Rightarrow \quad \Delta I_1 + \Delta I_2 + \Delta I_3 = 0$$

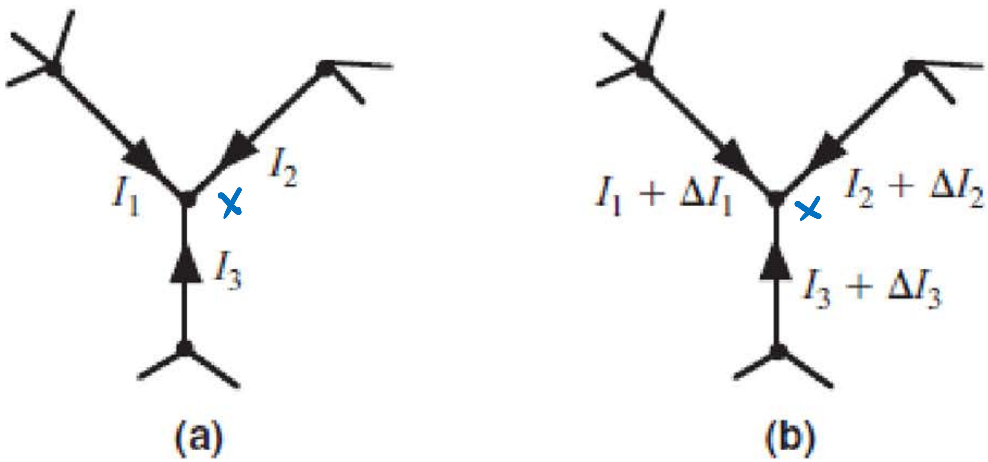


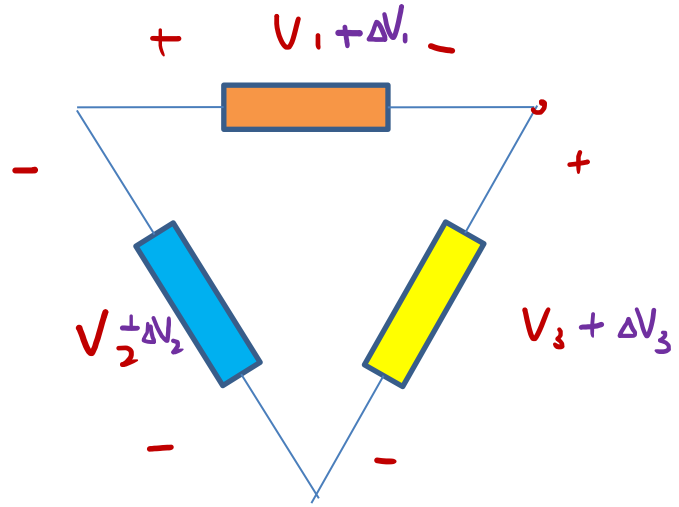
Figure 12.5 (a) The currents flowing into a node and; (b) new values of those currents following a change somewhere in the external circuit

Connections

KVL : $V_1 + V_2 + V_3 = 0$

$(V_1 + \Delta V_1) + (V_2 + \Delta V_2) + (V_3 + \Delta V_3) = 0$

$\Rightarrow \Delta V_1 + \Delta V_2 + \Delta V_3 = 0$



Model of Zener diode

$$V \longrightarrow V + \Delta V$$

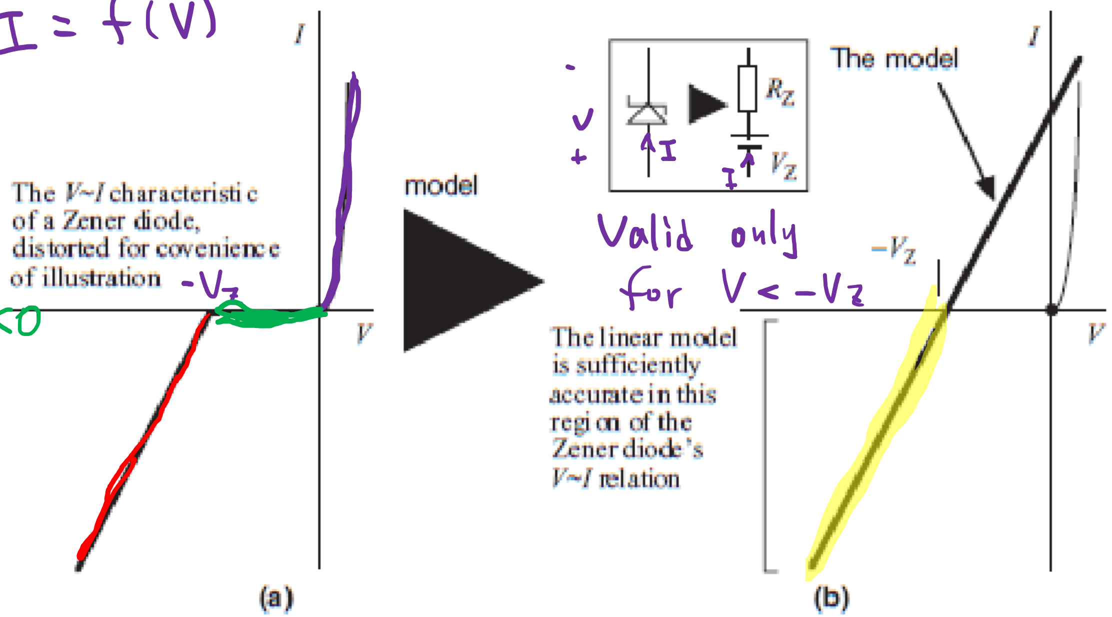
$$I \longrightarrow I + \Delta I = f(V + \Delta V)$$

$$\Delta V \sim \Delta I \ ?$$

nonlinear $I = f(V)$

$$I = \begin{cases} \dfrac{V+V_Z}{R_Z} & V < -V_Z \\ 0 & -V_Z < V < 0 \\ \sim e^{V/V_t} & V > 0 \end{cases}$$

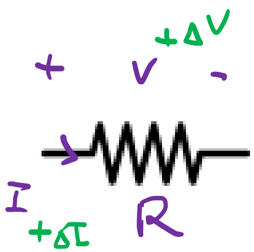
$V_Z - IR_Z = -V \Longrightarrow I = \dfrac{V+V_Z}{R_Z}$



Valid only for $V < -V_Z$

Figure 12.6 (a) The voltage~current characteristic of a Zener diode; (b), a linear model adequately representing the characteristic *in the region in which it is intended to operate*

Model of components



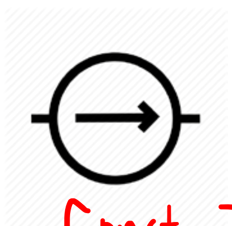
$$V = RI$$

$$V + \Delta V = R(I + \Delta I)$$

$$\Delta V = R\Delta I$$

Const V

$$\Delta V = 0$$



Const I

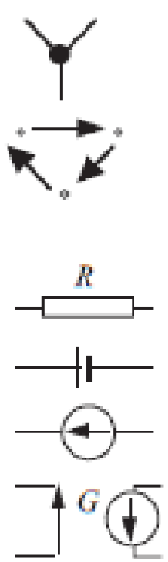
$$\Delta I = 0$$

Model of changes

Table 12.1 The component and connection relations for changes in current and voltage have the same form as do the same relations for DC currents and voltages

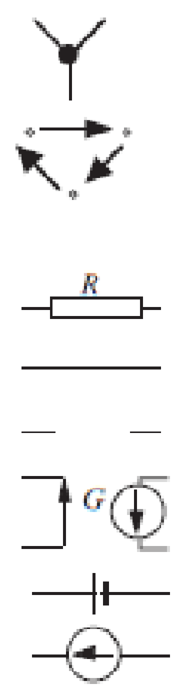
DC Currents and voltages | **Changes in current and voltage**

representation



relation (DC Currents and voltages)		*relation* (Changes in current and voltage)
	Connections	
$\sum_{node} I = 0$	*at node*	$\sum_{node} \Delta I = 0$
$\sum_{loop} V = 0$	*around loop*	$\sum_{loop} \Delta V = 0$
	Components	
$V = R\, I$	*resistor*	$\Delta V = R.\Delta I$
$V =$ constant	*voltage source*	$\Delta V = 0$
$I =$ constant	*current source*	$\Delta I = 0$
$I = GV$	*VCCS*	$\Delta I = G.\Delta V$
	voltage source change	$\Delta V =$ constant
	current source change	$\Delta I =$ constant

representation



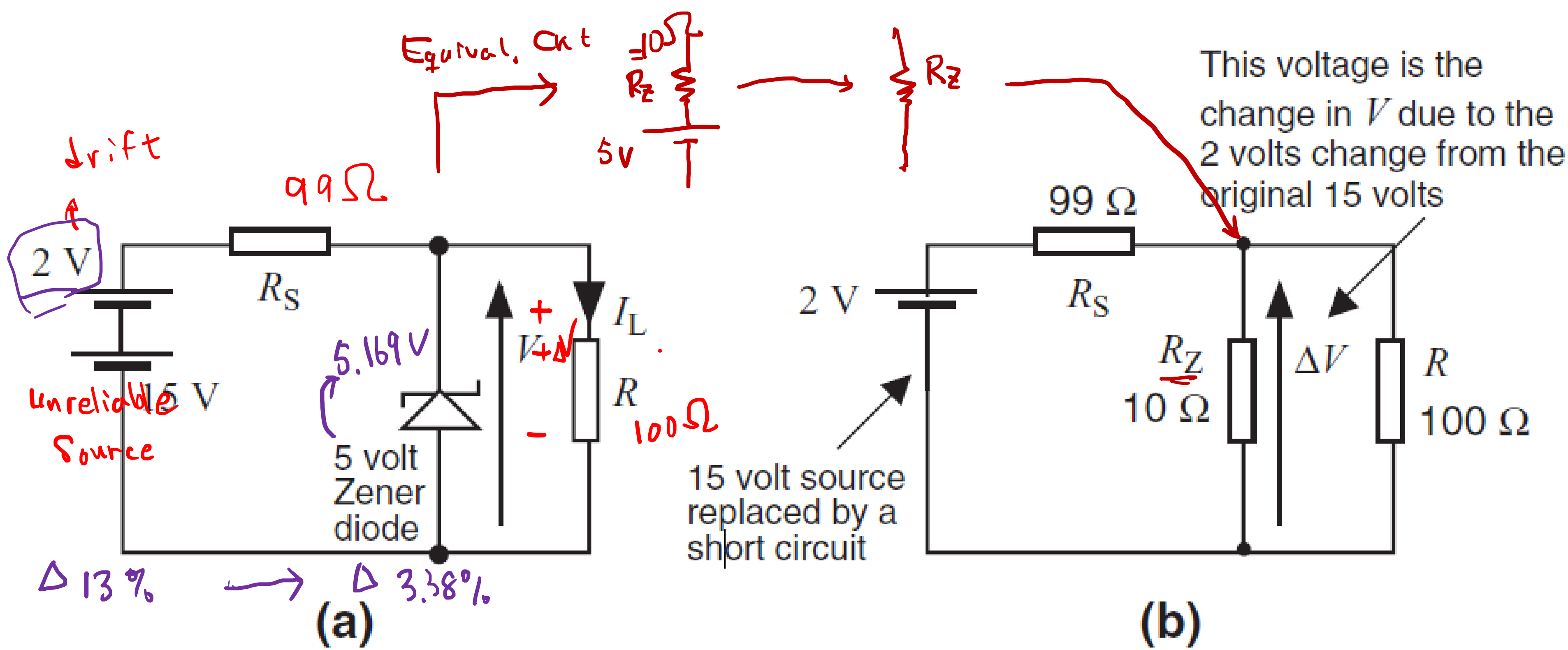
Example 12.1

Voltage source 15V change → (15+2)V

Load V=5V → V+ΔV

$\Delta V = ?$

Δ-Equivalent ckt: $\Delta V = 2 \times \frac{(10 // 100)}{99 + (10 // 100)} = 169 \text{ mV}$



Example 12.2

Increase in load current 10 mA

$\Delta I_L = 10$ mA $\longrightarrow$ $\Delta V = ?$

Δ - Equivalent Ckt

$$\Delta V = -10\text{ mA} \times (R \parallel R_Z \parallel R_S)$$

$$= -83.3\text{ mV}$$

1.67%

Original Load 50mA

↓ + 20% ΔI

+ ΔLoad = 60 mA

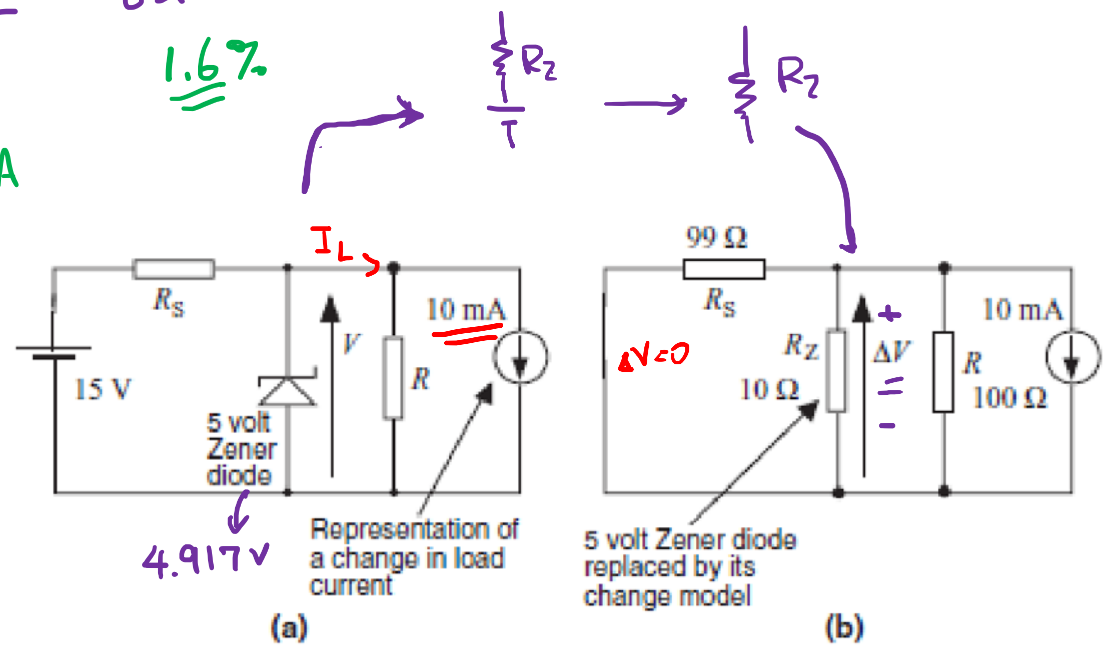
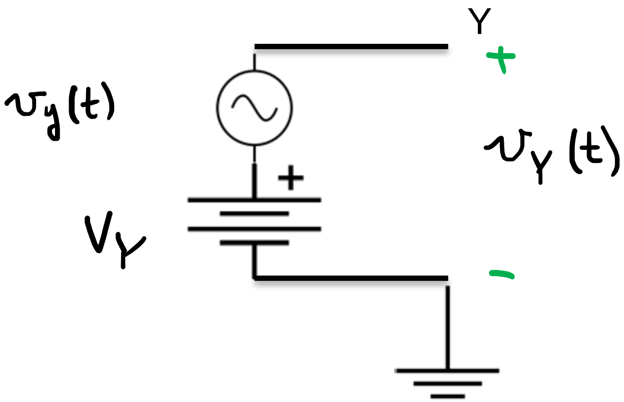
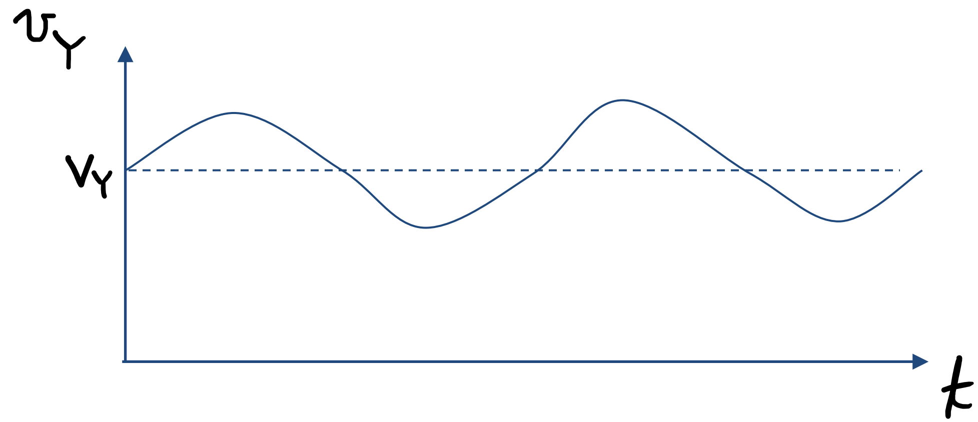


Figure 12.8 An actual circuit (a) and, (b), the change circuit relevant to the calculation of the effect of a 10 mA change in the load current

Chapter 13
Small-Signal Analysis

Notation!





$$v_Y(t) = V_Y + v_y(t)$$

Large-signal

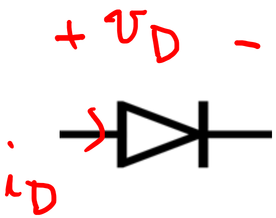
DC Bias

Small-signal

Ideal Diode

If $v_D > 0$ Forward bias $\quad i_D > 0$

If $v_D < 0$ Reverse bias $\quad i_D = 0$



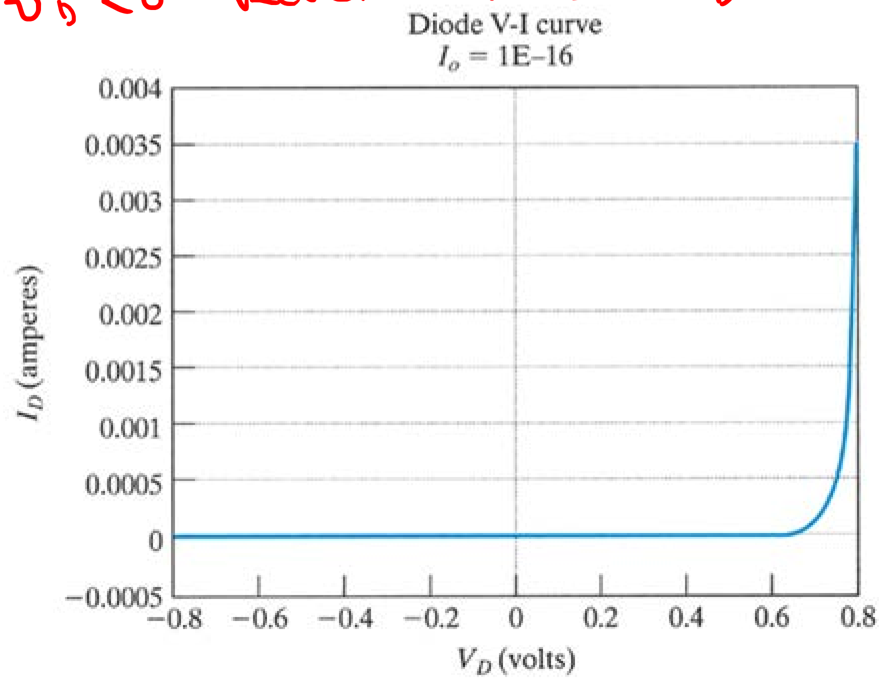


FIGURE 10.21 Plot of diode equation for $I_o = 1 \times 10^{-16}$ A.

Real-world Diode

Exponential Diode

$$\boxed{I_D = I_o\left(e^{\frac{qV_D}{kT}} - 1\right)}$$

$$\rightarrow \quad i_D(t) = I_s \cdot \left(e^{\left[\frac{v_D(t)}{V_T}\right]} - 1 \right)$$

$$\boxed{V_T \simeq 25\,mV}$$

$$\simeq I_s \cdot e^{v_D(t)/V_T}$$

Forward bias

$v_D(t)$ sufficient large

Incremental resistance

$+ \; v_D \; -$

$i_D \longrightarrow$

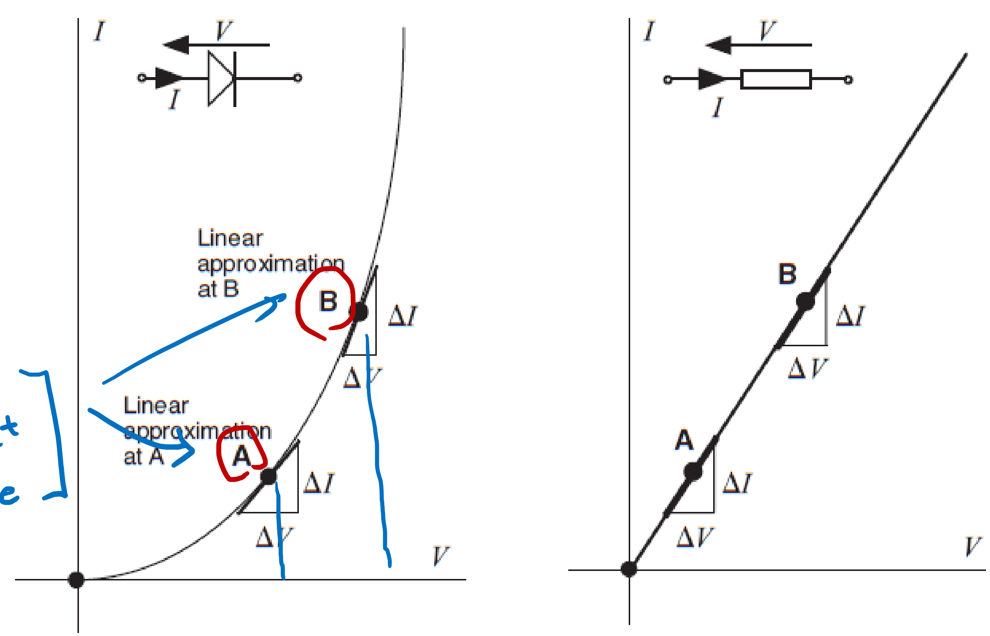
$$\begin{cases} i_D(t) = I_D + i_d(t) \\ v_D(t) = V_D + v_d(t) \end{cases}$$

$$v_d(t) \xrightarrow{?} i_d(t)$$

SMALL-SIGNAL ANALYSIS

Diode

Bias
Quiescent
Average



(a) (b)

Incremental resistance

$i_D(t)$, $+\ v_D(t)\ -$

I_D, $+\ V_D\ -$

$$\boxed{I_D = I_s \cdot e^{V_D/V_T}}$$

Linearity

Assume

$$\boxed{\frac{v_d}{V_T} \ll 1}$$

25 mV

$$i_D(t) \simeq I_s\, e^{v_D(t)/V_T}$$

$$I_D + \boxed{i_d(t)} = I_s\, e^{V_D + v_d(t)/V_T}$$

$$= \boxed{I_s\, e^{V_D/V_T}} \cdot e^{v_d(t)/V_T}$$

$$= \boxed{I_D} \cdot \left[1 + \frac{v_d(t)}{V_T} + \cancel{\frac{1}{2}\left[\frac{v_d(t)}{V_T}\right]^2} + \cdots\right] \to 0$$

$$\simeq I_D + \boxed{\frac{I_D}{V_T}\, v_d(t)}$$

$$\Rightarrow\ i_d(t) \simeq \frac{I_D}{V_T} \cdot v_d(t)$$

$+\ v_d(t)\ -$

$i_d(t)$

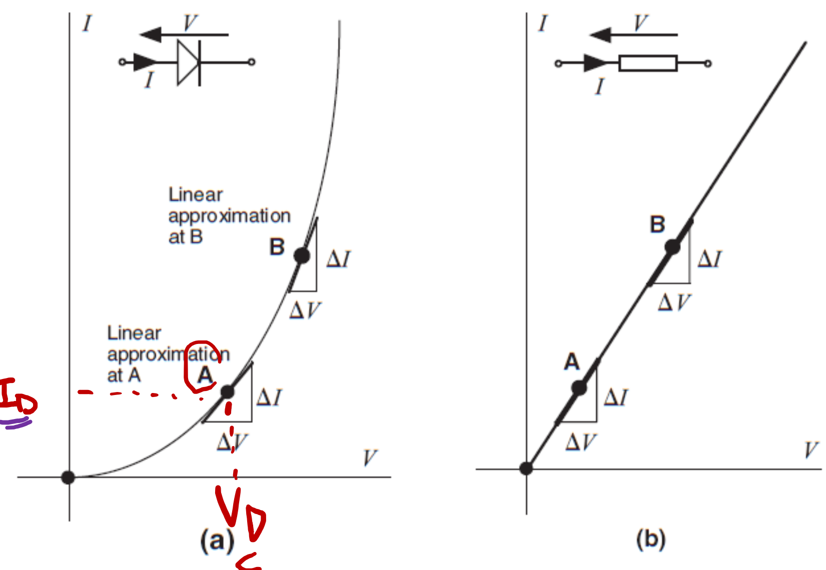
Equivalent $\equiv$

$+\ v_d(t)$

$i_d(t)$

$$r_d = \frac{V_T}{I_D}$$

I_D



Incremental resistance r_d

Alternative view (change analysis)

$$\left.\begin{array}{l} I_D \longrightarrow I_D + \Delta I \\ V_D \longrightarrow V_D + \Delta V \end{array}\right\} \quad \text{Relation of } \Delta V \sim \Delta I \ ?$$

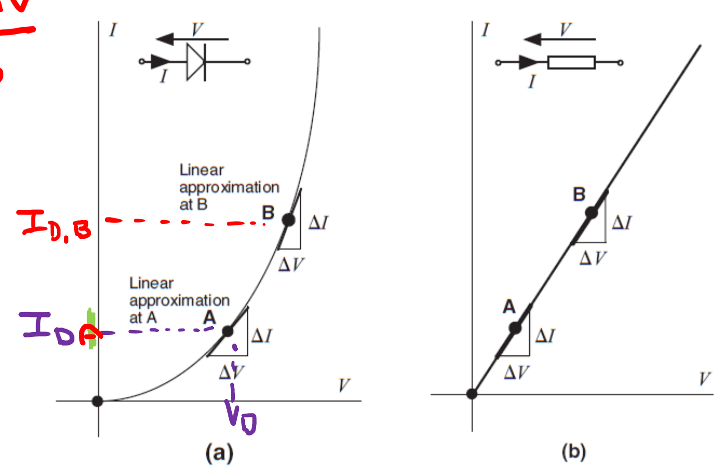
$$\frac{\Delta I}{\Delta V} \simeq \frac{d i_D}{d v_D} = \frac{d}{d v_D}\Big(\underbrace{I_s \cdot e^{\frac{v_D}{V_T}}}_{i_D}\Big)$$

$$= \frac{I_s}{V_T} e^{\frac{v_D}{V_T}} \simeq \frac{i_D}{V_T} \simeq \frac{I_D}{V_T}$$

define $g_d \equiv I_D / V_T$ [Incremental conductance]

$$r_d \equiv 1/g_d = \frac{V_T}{I_D} \simeq \frac{25\,mV}{I_D}$$

$$\Delta V = r_d \cdot \Delta I$$



Small-signal models

$$v_Y(t) = V_Y + v_g(t)$$

Changes in current and voltage

r_d

diode	$\Delta V = rd.\Delta I$	r_d
resistor	$\Delta V = R.\Delta I$	R
voltage source	$\Delta V = 0$	
current source	$\Delta I = 0$	
VCCS	$\Delta I = G\Delta V$	G
voltage source change	$\Delta V = \text{constant}$	
current source change	$\Delta I = \text{constant}$	

$$r_d = \frac{V_T}{I_D}$$

Source Bias

Small-signal source

Example 13.1

Find $v_D(t)$=?

$i_D = I_s e^{v_D/V_T}$

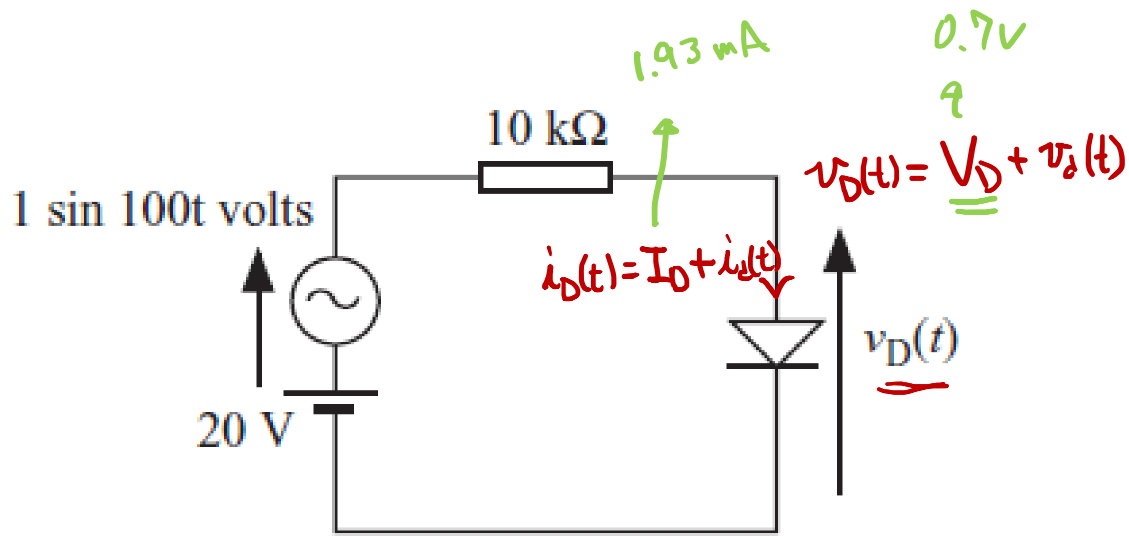
Source $v_s(t) = \underbrace{20}_{V_S\text{ : bias}} + \underbrace{1 \sin 100t}_{v_s(t)\text{ : small signal}}$

Step 1. Find DC bias (quiescent condition)

$V_D = 0.7V$

$V_s = 20V$

$I_D = \frac{20 - V_D}{10K} = 1.93\, mA$



Example 13.1

Step 2. Find small signal model

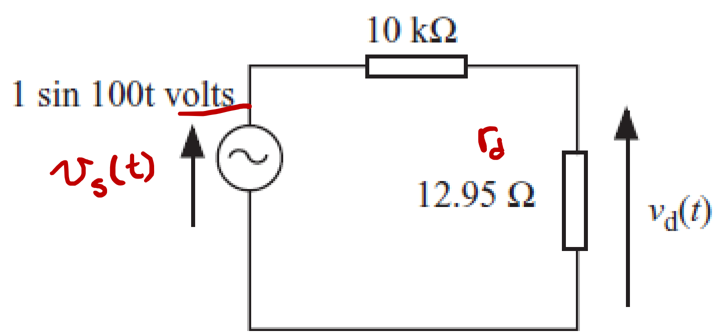
$$r_d = \frac{1}{g_d} = \frac{V_T}{I_D} = \frac{25\,mV}{1.93\,mA} \simeq 12.95\,\Omega$$

Step 3. Create small-signal equiv. ckt

Step 4. Analyze small-signal ckt

$$v_d(t) = v_s(t) \cdot \frac{r_d}{10k + r_d}$$

$$\simeq 1.29 \sin(100t) \ (mV)$$



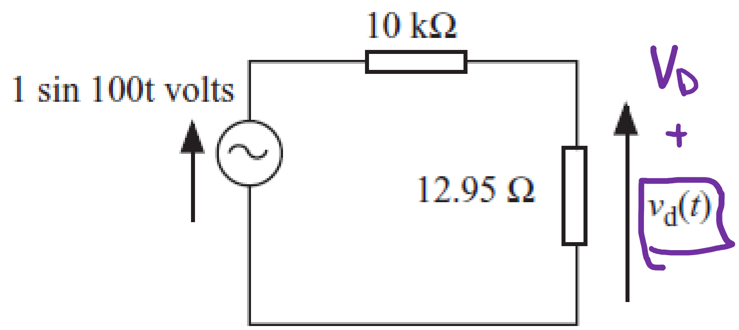
Example 13.1

Step 5. Check linearity assumption

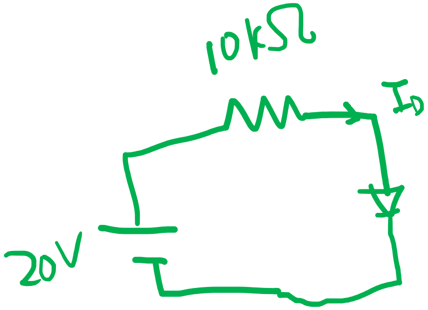
$$\left|\frac{v_d(t)}{V_T}\right| \leq \frac{1.29\ mV}{25\ mV} << 1$$

Total (large-signal) voltage across diode

$$v_D(t) = 0.7 + 0.00129 \sin(100t)$$



Example 13.1

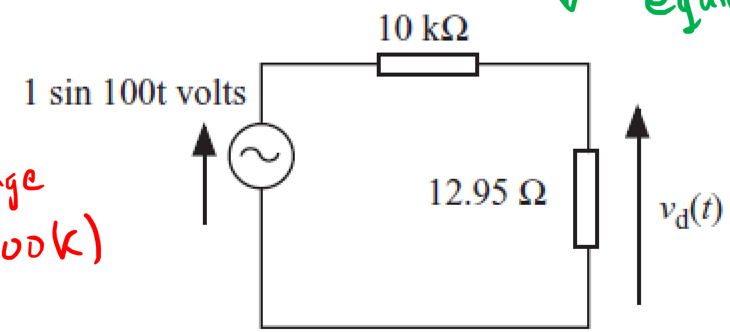


$I_D = \frac{20-0.7}{10k} = 1.93\ mA$ →

$g_d = \frac{I_D}{V_T}$

$r_d = \frac{V_T}{I_D} = \frac{25\ mV}{1.93\ mA} = 12.95$

Small-signal equiv.

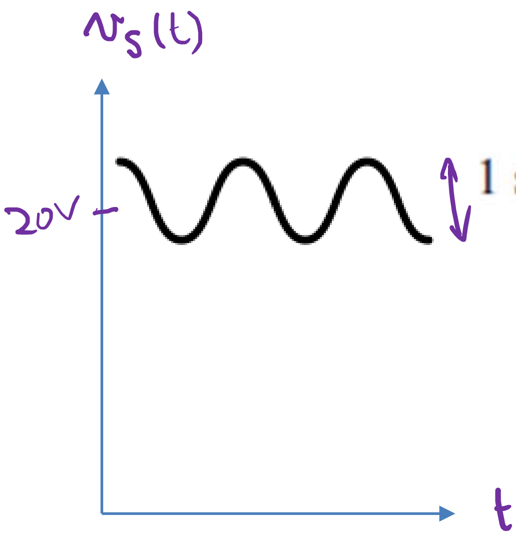


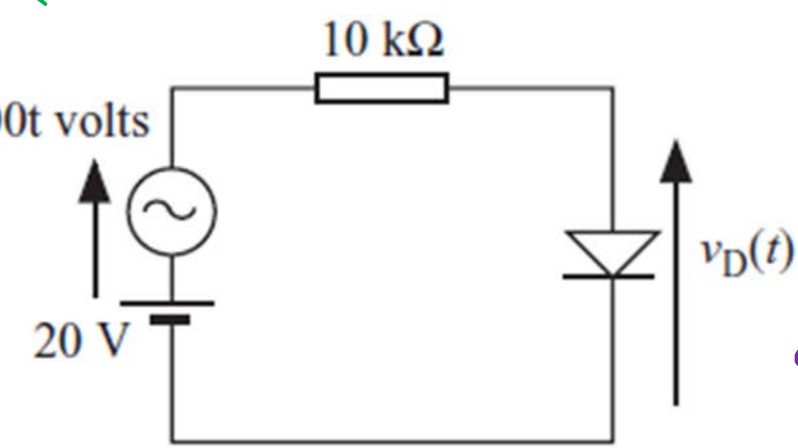
V_T : thermal voltage

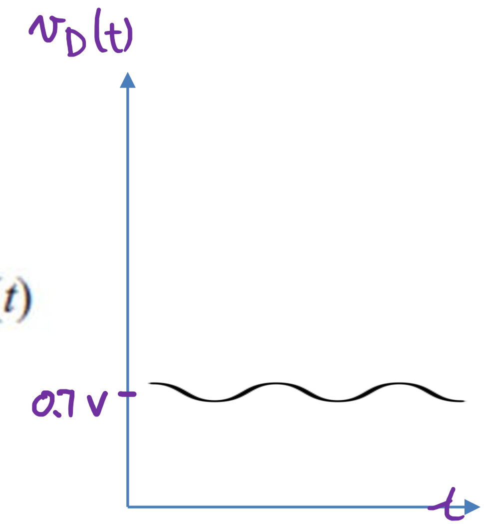
$\simeq 25\ mV$ (300K)

$V_D = 0.7V$

$\boxed{0.7} + 0.00129 \sin(100t)$







Chapter 13 Summary

Locally Linearization Approximation → Linear Analysis

Nonlinear →

Small-signal analysis = change analysis

$I = f(V)$ $I + \Delta I = f(V + \Delta V)$

$\Rightarrow \Delta I \cong \left(\frac{df}{dV}\right) \Delta V$

Diode $\frac{1}{r_d}$ or g_d

Linear approximation valid for

V_D : Sufficient high

$v_d \ll V_T$

(25 mV)

Course summary

Basic rules
KCL
KVL
Ohm's law

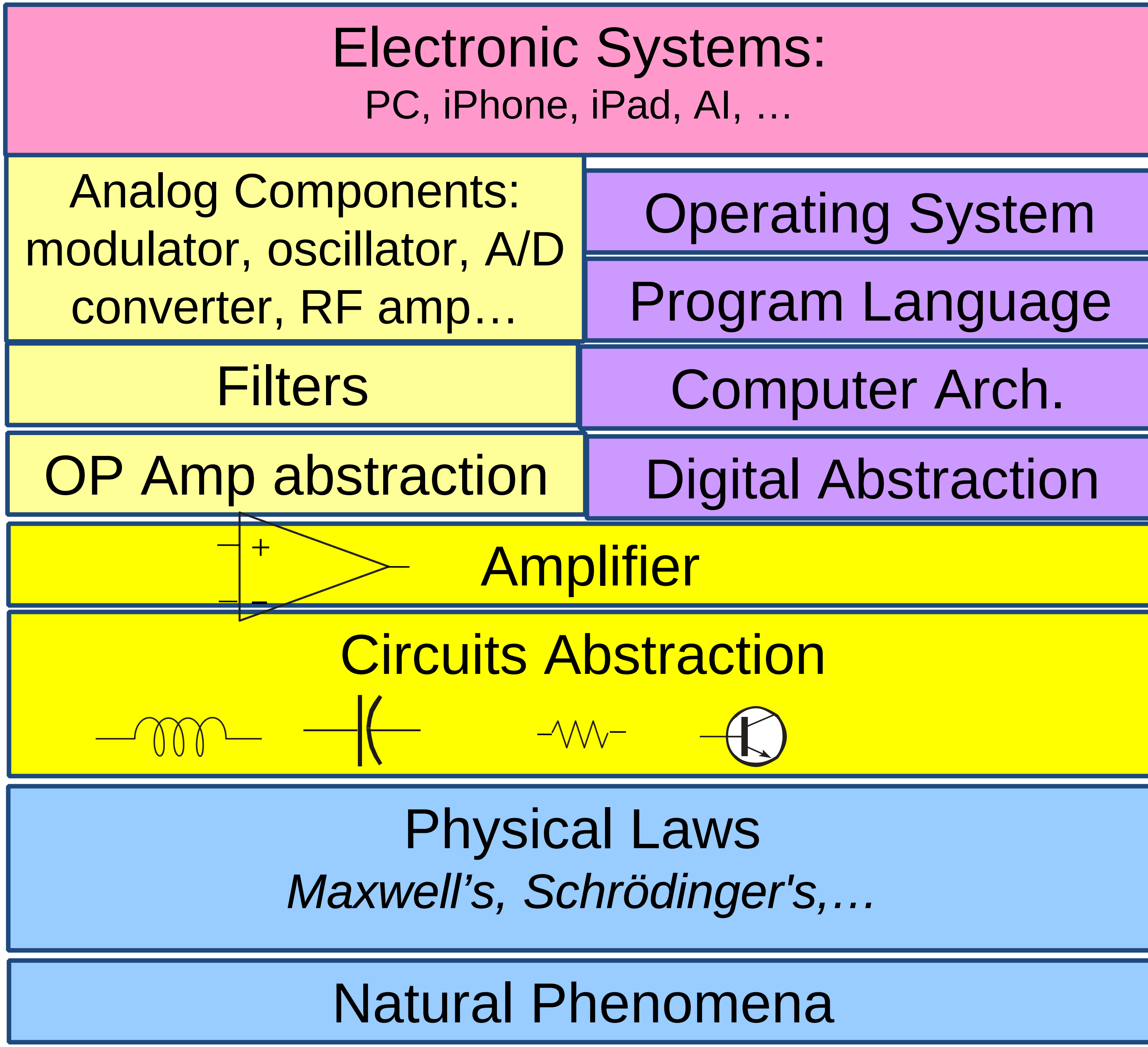
DC circuits
Nodal analysis
Superposition
Thevenin's equiv ckt
Norton's equiv ckt

Non-linear
Change analysis
Small-signal analysis

AC circuits
Phasor diagram
Complex impedance
Frequency response

OP amp
Positive feedback: trigger
Negative feedback: virtual short ckt

(dependent source)


Electronic Systems:
PC, iPhone, iPad, AI, …
Analog Components:
modulator, oscillator, A/D converter, RF amp…
Operating System
Program Language
Filters
Computer Arch.
OP Amp abstraction
Digital Abstraction
+
−
Amplifier
Circuits Abstraction
Physical Laws
Maxwell’s, Schrödinger's,…
Natural Phenomena