Last time: Operational amplifiers

Chapter 16

- Introduction
- An ideal operational amplifier
- Basic operational amplifier circuits
- Some other useful circuits
- Real operational amplifiers
- Selecting component values
- Effects of feedback on op-amp circuits

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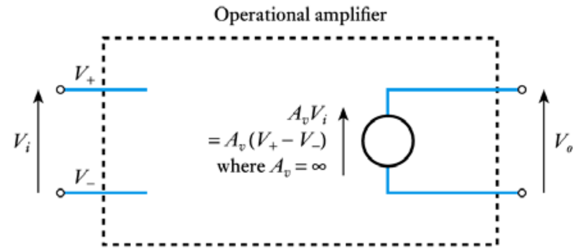
An ideal operational amplifier

16.2

- An *ideal* op-amp would be an ideal voltage amplifier and would have: $A_v = \infty$, $R_i = \infty$ and $R_o = 0$



Equivalent circuit of an ideal op-amp

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To analyse basic operational amplifier circuits

- Two Basic Rules

  1)An Op-Amp will do whatever is necessary with its output to adjust the voltage at its inverting input so that it is equal to the voltage at its non-inverting input. I.e. make the voltage difference between its inputs equal to zero. ($V_+ = V_-$)

  2)Op-Amp inputs draw no current (reality 0.2nA to fA). (*For an ideal op-amp $I_{in} = 0$*)

Horowitz, Paul and Hill, Winfred,The Art of Electronics, Cambridge University Press, 1980

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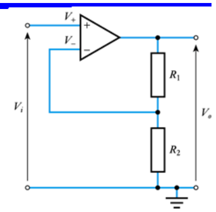
Basic operational amplifier circuits

- **A non-inverting amplifier**



Since the gain is assumed infinite, if V_o is finite there is no difference in input voltages (Rule1).

Hence: $V_- = V_+ = V_i$

Since the input resistance of the op-amp is ∞ no current flows into it from the feedback loop (Rule 2)

$$V_- = V_o \frac{R_2}{R_1 + R_2}$$

and hence, since $V_- = V_+ = V_i$

$$V_i = V_o \frac{R_2}{R_1 + R_2} \quad \text{and} \quad G = \frac{V_o}{V_i} = \frac{R_1 + R_2}{R_2}$$

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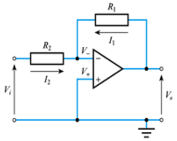
16.3.2

- **An inverting amplifier**

Since the gain is assumed infinite, if V_o is finite the input voltage must be zero. Hence



$$\boxed{V_- = V_+ = 0 \quad (Rule\ 1)}$$

Since the input resistance of the op-amp is ∞ its input current must be zero. Hence (applying KCL)

$$I_1 + I_2 - I_{in-} = 0 \qquad But\ as\ \boxed{I_{in-} = 0\ \ (Rule\ 2)\ \Rightarrow I_1 = -I_2}$$

Now

$$I_1 = \frac{V_o - V_-}{R_1} = \frac{V_o - 0}{R_1} = \frac{V_o}{R_1} \qquad I_2 = \frac{V_i - V_-}{R_2} = \frac{V_i - 0}{R_2} = \frac{V_i}{R_2}$$

$$I_1 = -I_2 \Rightarrow \frac{V_o}{R_1} = -\frac{V_i}{R_2} \Rightarrow \boxed{G = \frac{V_o}{V_i} = -\frac{R_1}{R_2}}$$

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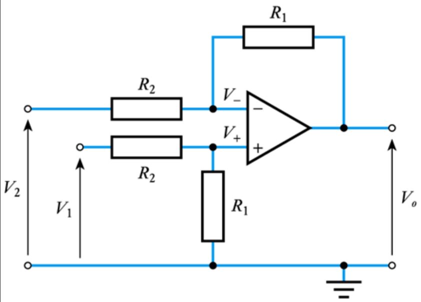
16.4.3

- **A differential amplifier (or subtractor)**



V_+ has changed from the previous analysis (where it was 0). Now: $V_+ = V_1 {*} R_1/(R_1+R_2)$ which must $=V_-$

the algebra from before with $V_i = V_2$, and $V_- = V_+$ as above, yields:

$$V_o = (V_1 - V_2)\frac{R_1}{R_2}$$

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Last time: Operational amplifiers

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Some other useful circuits

Video 16B

16.4

- In addition to simple amplifiers, op-amps can also be used in a range of other circuit
- The next few slides show a few examples of op-amp circuits for a range of purposes
- The analysis of these circuits is similar to that of the non-inverting and inverting amplifiers but (in most cases) this is *not* included here (clues to analysis are)
- For more details of these circuits see the relevant section of the course text (as shown on the slides)

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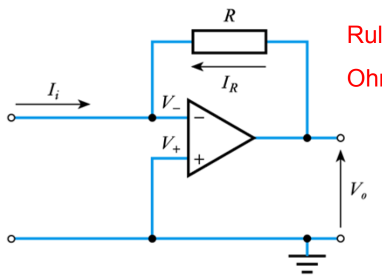
16.4.2

- **A current to voltage converter**



KCL → $I_i + I_R - I_{in-} = 0$

Rule 2 → $I_{in-} = 0$

Ohms law → $I_R = V_o / R$

$$V_o = -I_i R$$

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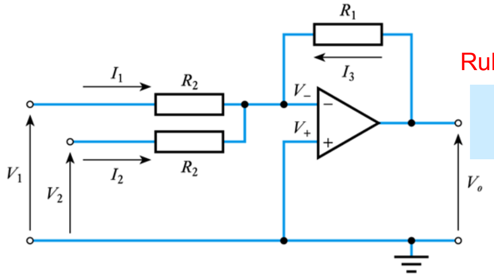
16.4.4

- **An inverting summing amplifier**



Virtual Ground, KCL:

$I_1 + I_2 + I_3 - I_{in-} = 0$

Rule 2: $I_{in-} = 0$

$$V_o = -(V_1 + V_2)\frac{R_1}{R_2}$$

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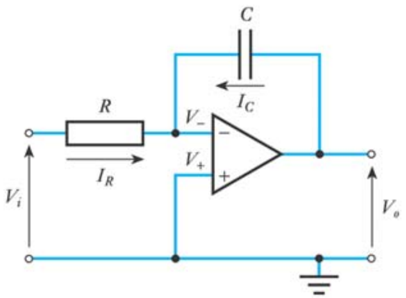
16.4.5

- **An integrator**



Since $I_c + I_R = 0$ (Rule 2)

$I_c = -V_i / R$

Since $V_- = V_+ = 0$ (Rule 1)

$V_o = V_c$

$$v_c(t) = \frac{1}{C}\int_0^t i_c(t')dt'$$

$$V_o = -\frac{1}{RC}\int_0^t V_i dt$$

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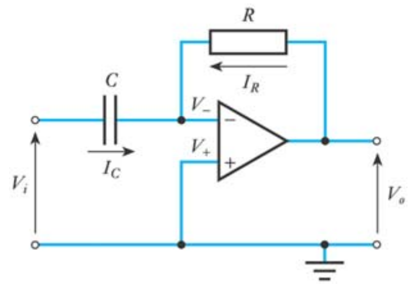
16.4.6

- **A differentiator**



Since $I_c + I_R = 0$ (Rule 2)

$I_c = -V_o / R$

Since $V_- = V_+ = 0$ (Rule 1)

$V_i = V_c$

$$i_c(t) = C\frac{dv_c(t)}{dt}$$

$$V_o = -RC\frac{dV_i}{dt}$$

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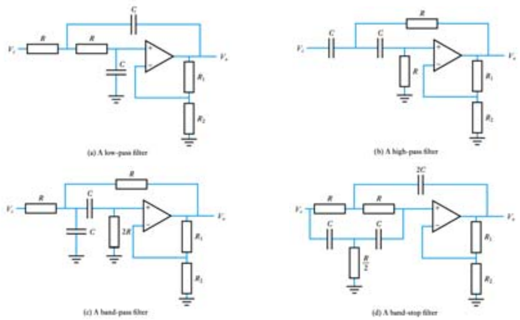
16.4.7

- **Active filters**



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Real vs. Ideal Op-Amps

Parameter	Ideal Op Amp	Typical Op Amp	741
Differential voltage gain A_d	∞	10^5 - 10^9	2×10^5
Common mode voltage gain A_{cm}	0	0.2-60	6.3-63
Gain bandwidth product $f_c = G \cdot f$	∞	1-20 MHz	1.5 MHz
Input resistance R	∞	10^6 Ω (bipolar) 10^9 - 10^{12} Ω (FET)	300 kΩ-2MΩ
Output resistance R	0	100-1000 Ω	75 Ω

Simpson, Robert E., Introductory Electronics for Scientists and Engineers, 2nd Ed., Allyn and Bacon, 1987

Typically give Common Mode Rejection Ratio (CMRR) = A_d/A_{cm}

For the 741 op amp this about 3200-32000 (70 to 90 dB)

Close enough to ideal that we can analyse circuits assuming ideal op-amps

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Selecting component values

16.6

- Our analysis assumed the use of an ideal op-amp
- When using real components we need to ensure that our assumptions are valid
- In general this will be true if we:
  - limit the *gain of our circuit*, G, to *much less* than the *open-loop gain of our op-amp*, A
  - choose external resistors that are *small* compared with the *input* resistance of the op-amp
  - choose external resistors that are *large* compared with the *output* resistance of the op-amp.
- Generally we use resistors in the range 1 to 100 kΩ

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Effects of feedback on op-amp circuits

16.7

- **Effects of feedback on the gain**
  - negative feedback *reduces* gain from *A* to *A*/(1 + *AB*)
  - in return for this loss of gain we get consistency, provided that the open-loop gain is much greater than the closed-loop gain (that is, *A* >> 1/*B*)
  - using negative feedback, standard cookbook circuits can be used – greatly simplifying the design
  - these can be analysed without a detailed knowledge of the op-amp itself

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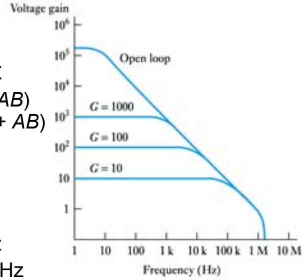
Video 16C

Effects of feedback on frequency response

- as the gain is *reduced* the bandwidth is *increased*
- gain × bandwidth ≈ constant
  - since gain is *reduced* by (1 + *AB*) bandwidth is *increased* by (1 + *AB*)



- for a 741,
  gain × bandwidth ≈ 10^6
  - if gain = 1000 BW ≈ 1000 Hz
  - if gain = 100 BW ≈ 10,000 Hz

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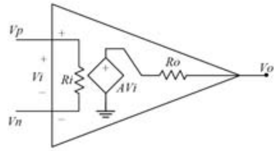
Video 16D

Effects of feedback on input and output resistance

- input/output resistance can be increased or decreased depending on how feedback is used
  - in each case the resistance is changed by a factor of (1 + *AB*)
- Looking towards R_{in} from the source, or R_{out} from the load
  parallel path to ground lowers effective impedance
  series path to ground raises effective impedance



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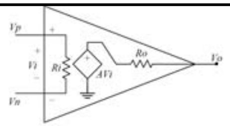
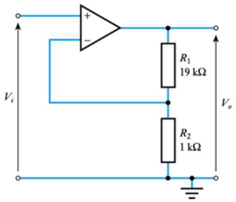


Example (see Example 16.5 in the course text)

- determine the input and output resistance of the following circuit assuming op-amp is a 741



Open-loop gain (*A*) of a 741 is 2×10^5
Closed-loop gain (1/*B*) is 20, *B* = 1/20 = 0.05
(1 + *AB*) = (1 + 2 × 10^5 × 0.05) = 10^4
Feedback senses output *voltage* therefore it *reduces* output resistance of op-amp (75 Ω) by 10^4 to give 7.5 mΩ
Feedback subtracts a *voltage* from the input, therefore it *increases* the input resistance of the op-amp (2 MΩ) by 10^4 to give 20 GΩ

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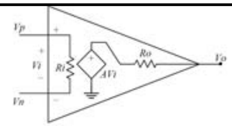

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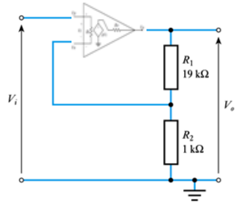

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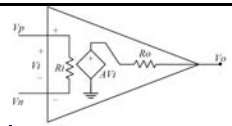
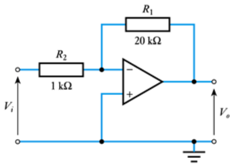


- **Example** (see **Example 16.6** in the course text)
  - determine the input and output resistance of the following circuit assuming op-amp is a 741



Open-loop gain (A) of a 741 is 2×10^5
Closed-loop gain ($1/B$) is 20, $B = 1/20 = 0.05$
$(1 + AB) = (1 + 2 \times 10^5 \times 0.05) = 10^4$
Feedback senses output *voltage* therefore, it *reduces* output resistance of op-amp (75 Ω) by 10^4 to give 7.5 mΩ
Feedback subtracts a *current* from the input, therefore it *decreases* the input resistance. In this case the input sees R_2 to a virtual earth, therefore the input resistance is 1 kΩ

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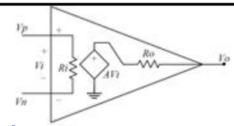

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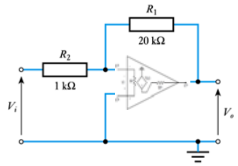
  - determine the input and output resistance of the following circuit assuming op-amp is a 741



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Further Study

Video 16E

Further Study

- The Further Study section at the end of Chapter 16 looks at the identification of op-amp circuits.
- Normally our task is to design a circuit to perform a given task. However, it is also useful to be able to look at a circuit and see what it does!

- Look at the circuits given in the text and see if you can work out their function. Then look at the video to see if you are correct.

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Key points

- Operational amplifiers are among the most widely used building blocks in electronic circuits
- An *ideal* operational amplifier would have infinite voltage gain, infinite input resistance and zero output resistance
- Designers often make use of cookbook circuits
- Real op-amps have several non-ideal characteristics However, if we choose components appropriately this should not affect the operation of our circuits
- Feedback allows us to increase bandwidth by trading gain against bandwidth
- Feedback also allows us to alter other circuit characteristics

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Semiconductors and diodes

Chapter 17

- Introduction
- Electrical properties of solids
- Semiconductors
- *pn* Junctions
- Diodes
- Semiconductor diodes
- Special-purpose diodes
- Diode circuits.

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Introduction

17.1

- So far we have taken a '**black-box**' view of active components (such as op-amps)
- It is now time to look 'inside the box'
  - we will start by looking at diodes and semiconductors
  - then progress to transistors
  - later, we will look at more detailed aspects of circuit design

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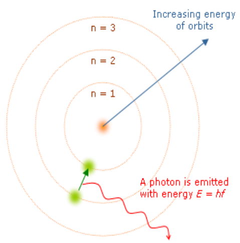
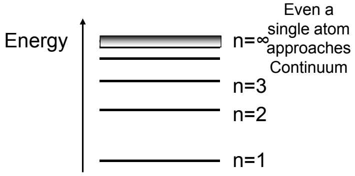
Quantum Mechanical Electronic energy levels in atoms

- The electrons have discrete energy levels
- Form a continuum band at high quantum number

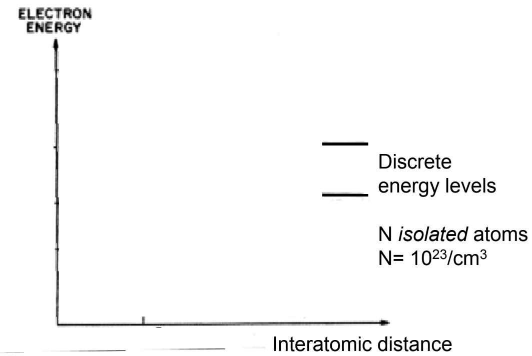
(Like the steps in a ladder, but with uneven distance between the steps.)

Bohr's atom model





Electronic energy levels in solids, N atoms



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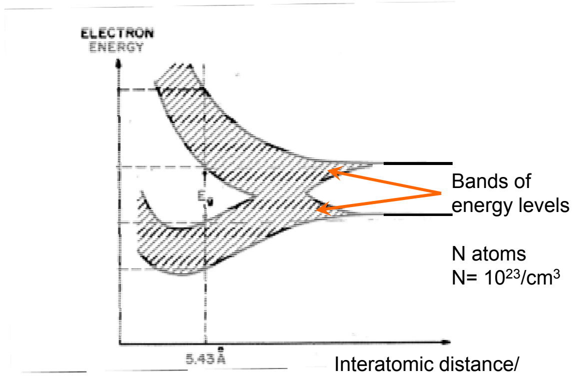
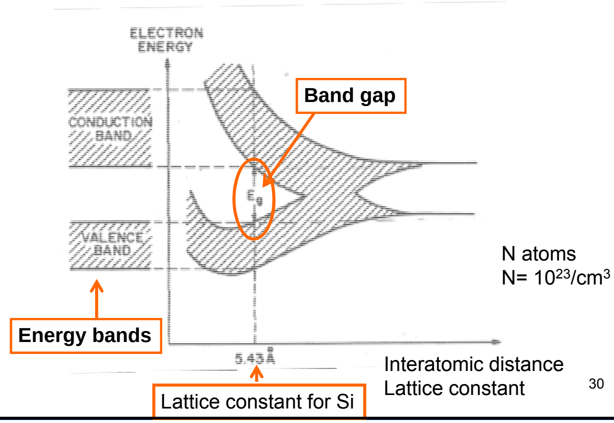
Electronic energy levels in solids, N atoms



29

Electronic energy levels in solids, N atoms



30

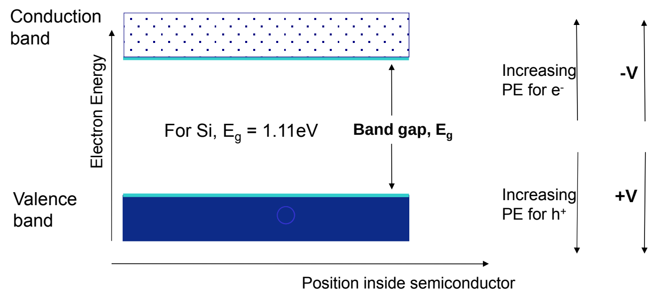
The "band diagram" tells you which energy levels are available, not if they are occupied by electrons or not….

If the levels are occupied or not, depends on the number of electrons available; i.e. on the type of atom….

(…and on the external energy available)

31

Energy Level Diagrams



At absolute zero, all charges in valence band, E_v (Mean Sea Level)

32

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The Fermi distribution and the Fermi level

- The probability that an electronic state with energy E is occupied by an electron is given by the Fermi-Dirac distribution function (also called the Fermi distribution)

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

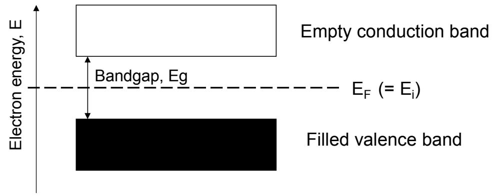
where k is the Boltzmann constant, T the absolute temperature and E_F the Fermi level.

The Fermi level is the energy at which the probability of occupation by an electron is exactly one half.

$f(E_F) = 0.5$

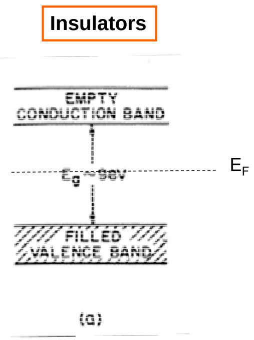
Fermi level in undoped semiconductors

- In an undoped semiconductor in thermal equilibrium at zero Kelvin, all electronic states with energy up till the top of the valence band (the valence band edge) are occupied (filled), and all electronic states above the bottom of the conduction band are empty

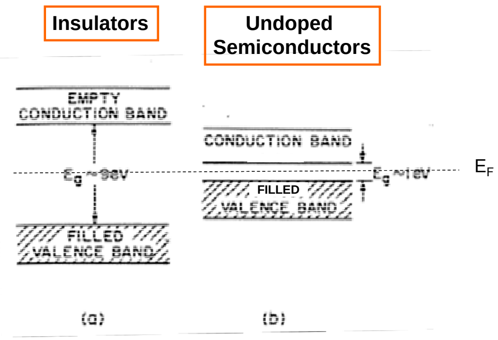


- There is 100% probability of finding an electron in the valence band and 0% probability to find an electron in the conduction band, so the Femi level (the energy of 50% probability) is in the middle of the bandgap.

Band separation and electronic properties



Band separation and electronic properties



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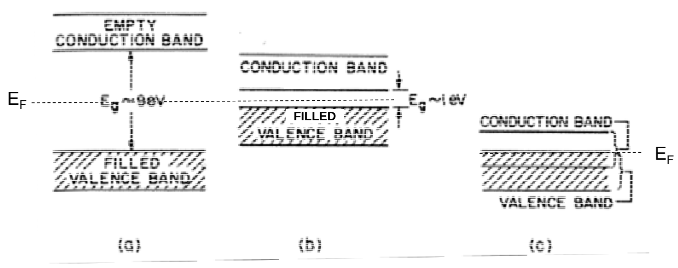
Band separation and electronic properties

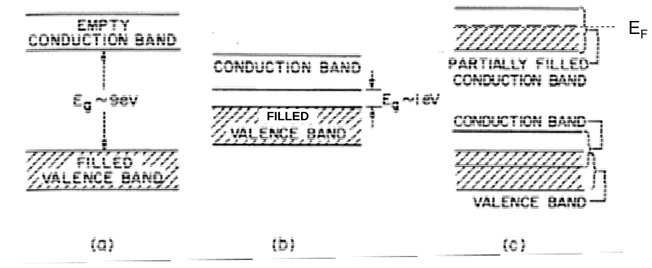
Insulators | **Undoped Semiconductors** | **Metals**



37

Band separation and electronic properties

Insulators | **Undoped Semiconductors** | **Metals**



38

Electrical properties of solids

17.2

- **Conductors**
  – e.g. copper or aluminium
  – have a cloud of free electrons (at all temperatures above absolute zero). If an electric field is applied electrons will flow causing an electric current
- **Insulators**
  – e.g. polythene
  – electrons are tightly bound to atoms, so, only a few can break free to conduct electricity

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- **Semiconductors**
  – e.g. silicon or germanium
  – at very low temperatures these have the properties of insulators
  – as the material warms up some electrons break free and can move about, and it takes on the properties of a conductor – albeit a poor one
  – however, semiconductors have several properties that make them distinct from conductors and insulators

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Semiconductors

17.3

- **Pure semiconductors**
  - thermal vibration results in some bonds being broken, generating **free electrons** which move about
  - these leave behind **holes** which accept electrons from adjacent atoms and therefore, also move about
  - electrons are **negative charge carriers**
  - holes are **positive charge carriers**
- At room temperatures there are few charge carriers
  - *pure* semiconductors are poor conductors
  - this is **intrinsic conduction**

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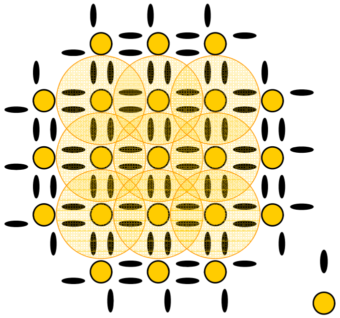
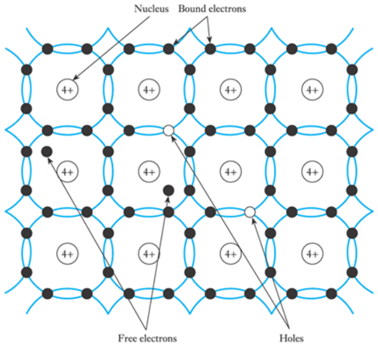
Pure Silicon

The outermost shell of Si, the so called valence shell, can hold 8 electrons
Each Si atom has only 4 valence electrons (electrons in the outermost shell).
Each Si atom then shares 4 valence electrons with its nearest neighbours, so that it has 8 in total (and has filled the outer shell).



Pure silicone: thermal effect-partially conducts

- The effect of thermal vibration on the structure of silicon-occasional electron-hole pairs generated
- Want to enhance this effect by adding impurities in a process called "doping"



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Doping of semiconductors

- **Doping**
  - the addition of small amounts of impurities drastically affects its properties
  - some materials form an excess of *electrons* and produce an ***n*-type semiconductor**
  - some materials form an excess of *holes* and produce a ***p*-type semiconductor**
  - both *n*-type and *p*-type materials have much greater conductivity than pure semiconductors
  - this is **extrinsic conduction**

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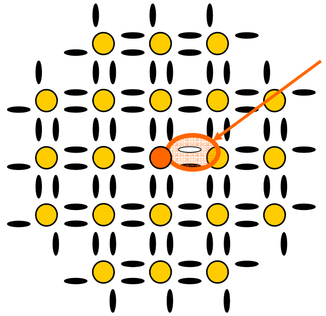
P-doping

Replace one silicon atom with an atom that has only three valence electrons (i.e. boron) (and also one less proton in the core).



A hole, that can be filled by nearby electrons, When that happens the dopant is ionized, and negatively charged.

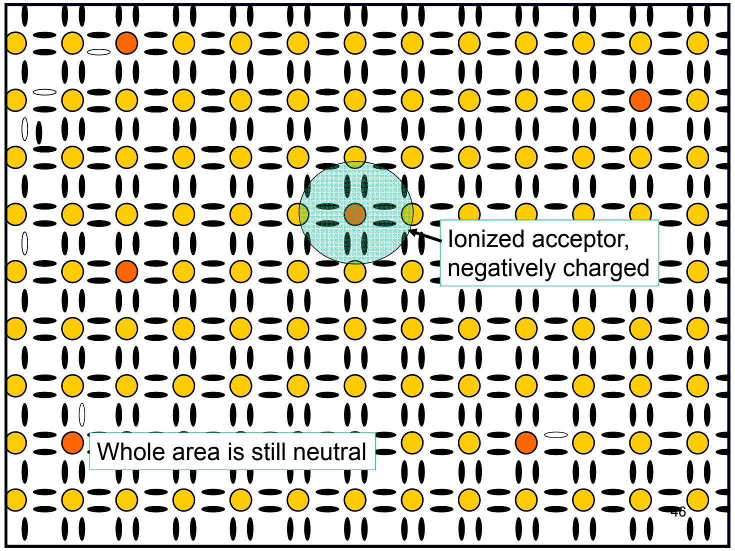
Note the Si atom that donated the electron now lacks one, so it has a positive charge, making the whole material neutral

Binding electrons, keeping the material together

Si nucleus + electrons in filled shells (that do not take part in the bonding)

The p-dopant can accept electrons from the silicon atoms, and are called acceptors.

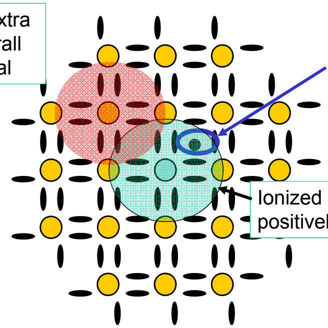
45



N-doping

Replace one silicon atom with an atom that has five valence electrons (i.e. phosphorus) (and also one proton more in the core).

This Si has an extra electron, so overall material is neutral



An excess (free) electron not participating in the bonding process

Ionized donor, positively charged

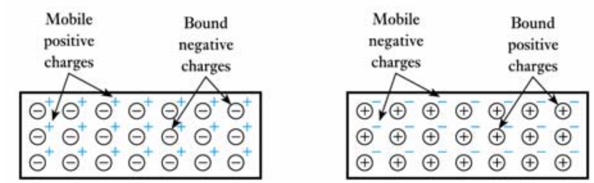
Binding electrons, keeping the material together

Si nucleus + electrons in filled shells (that do not take part in the bonding)

47

Conduction electrons

- The dominant charge carriers in a doped semiconductor (e.g. electrons in *n*-type material) are called **majority charge carriers**. The other type are **minority charge carriers**
- The overall doped material is electrically neutral



(a) *p*-type semiconductor (b) *n*-type semiconductor

17.48

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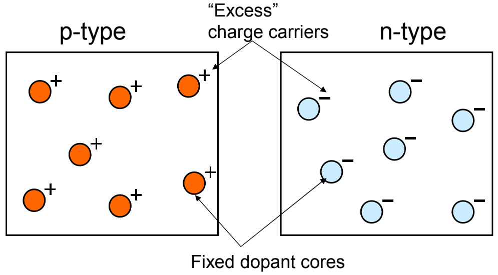
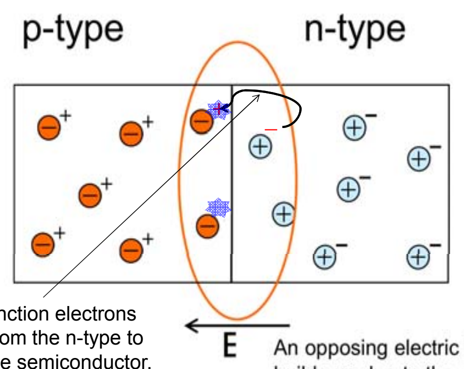
pn-junction

To create an built-in electric field : join a p-type and an n-type semiconductor, to create a pn-junction.



Here shown before ionization of the dopants; In the ionization process the free carriers will be (thermally) released to the surrounding semiconductor.

What happens when the p- and n-type materials are brought together?



At the junction electrons diffuse from the n-type to the p-type semiconductor, where they recombine with available holes. This creates a depletion of free charges.

An opposing electric field builds up due to the charge associated with the ionized donor and acceptor atoms.

This electric field stops the diffusion. But any thermal electrons generated more towards n-type

17.4

pn Junctions

- When *p*-type and *n*-type materials are joined, this forms a ***pn* junction**
  - the majority charge carriers on each side diffuse across the junction where they combine with (and remove) the charge carriers of the opposite polarity
  - hence, around the junction there are few free charge carriers and we have a **depletion layer** (also called a **space-charge layer**)

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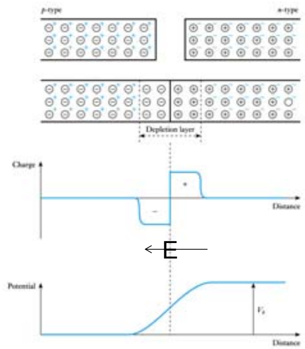
- The diffusion of positive charge in one direction and negative charge in the other produces a charge imbalance
  - this results in an Electric Field and **potential barrier** across the junction



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- **Potential barrier**
  - the barrier opposes the flow of *majority* charge carriers and only a small number have enough energy to surmount it
    - This generates a *small* **diffusion current**
  - the barrier encourages the flow of *minority* carriers and any that come close to it will be swept over
    - This generates a small **drift current**
  - for an isolated junction these two currents must balance each other and the net current is zero

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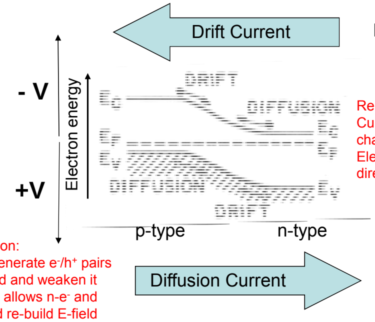
Currents at Equilibrium

- The Drift and Diffusion currents are = and opposite: $J_t = J_{drift} - J_{diffusion} = 0$



Due to E field

Remember:
Current is defined as motion of + charge carriers,
Electrons move in opposite direction

Constant charge motion:
- Thermal events generate e⁻/h⁺ pairs They drift in E-field and weaken it
- Weakened E-field allows n-e⁻ and p-h⁺ to diffuse and re-build E-field
- Diffusion cancels drift: no net current

Due to n/p Concentration gradients

Biasing the *pn* Junction

- **Forward bias**
  - if the *p*-type side is made *positive* with respect to the *n*-type side the height of the barrier is reduced
  - more majority charge carriers have sufficient energy to surmount it
  - the diffusion current therefore increases while the drift current remains the same
  - there is thus a net current flow across the junction which increases with the applied voltage

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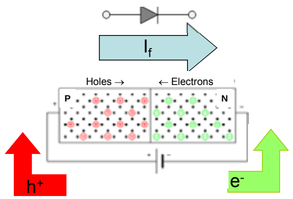
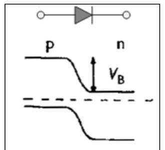
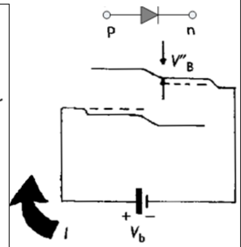
Biasing of the p-n junction



Forward battery bias:
- *pushes h^+ into p side, e^- into n side*
- *this repels other majority carriers toward junction,*
- *recombination there results in battery current.*



Isolated junction
Zero bias



Forward bias
$V''_B < V_b$

Forward Bias-reduce V_B
$V''_B = V_B - |V_b|$

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Reverse bias

- if the *p*-type side is made *negative* with respect to the *n*-type side the height of the barrier is increased
- the number of majority charge carriers that have sufficient energy to surmount it rapidly decreases
- the diffusion current therefore vanishes while the drift current remains the same
- thus the only current is a small leakage current caused by the (approximately constant) drift current
- the leakage current is usually negligible (a few nA)

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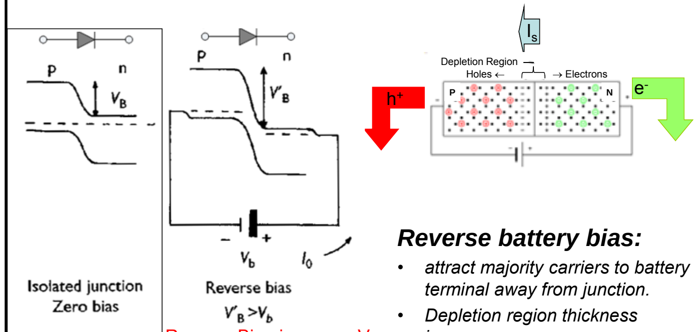
Biasing of the p-n junction



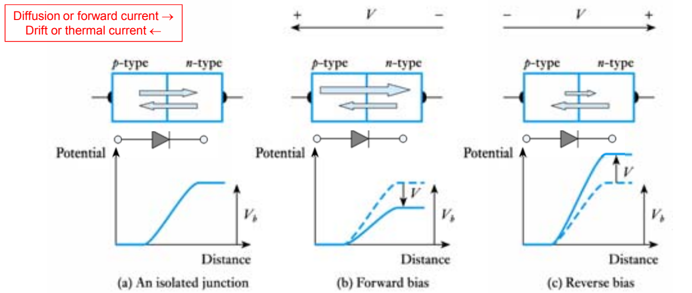
Reverse Bias-increase V_B

$V'_B = V_B + |V_b|$

Reverse battery bias:

- *attract majority carriers to battery terminal away from junction.*
- *Depletion region thickness increases.*
- *No sustained battery current flows*
- *Only random thermal events supply I_s*

Currents in a *pn* junction



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Forward and reverse currents

- *pn* junction current is given approximately by

$$I = I_s\left(\exp\frac{eV}{\eta kT} - 1\right)$$

- where I is the current, e is the electronic charge, V is the applied voltage, k is Boltzmann's constant, T is the absolute temperature and η (Greek letter *eta*) is a constant in the range 1 to 2 determined by the junction material
- for most purposes we can assume η =1

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- Thus,

$$I \approx I_S\left(\exp\frac{eV}{kT} - 1\right)$$

at room temperature $e/kT \sim 40\ \mathrm{V}^{-1}$

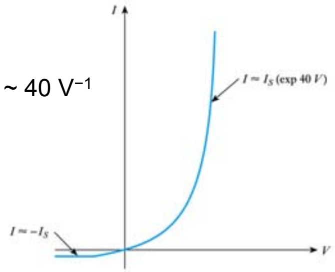
- If $V > +0.1$ V,

$$I \approx I_s\left(\exp\frac{eV}{kT}\right) = I_s(\exp 40V)$$

- If $V < -0.1$ V,

$$I \approx I_s(0-1) = -I_s$$

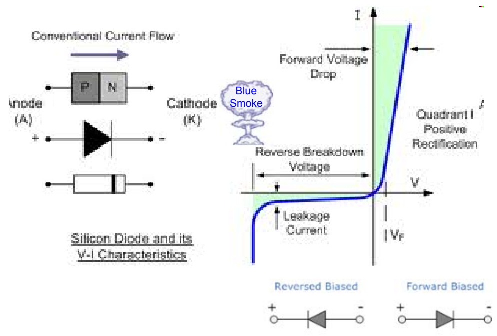
– I_S is the **reverse saturation current**



That is, our drift or thermal current, I_s

External currents across a pn-junction

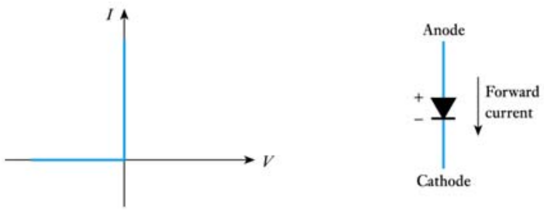
- The diode passes current in one direction.



Diodes

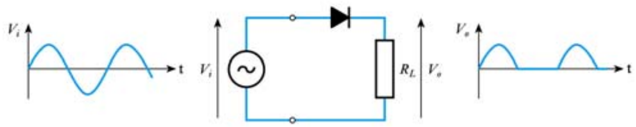
17.5

- An **ideal diode** passes electricity in one direction but not in the other



(a) I–V characteristic (b) Diode circuit symbol

- One application of diodes is in **rectification**
  - the example below shows a **half-wave rectifier**



- In practice, no real diode has ideal characteristics but semiconductor ***pn* junctions** make good diodes

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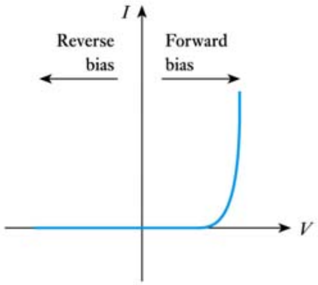
17.6

Semiconductor diodes

- **Forward and reverse currents**



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- **Silicon diodes**
  - generally have a turn-on voltage of about 0.5 V
  - generally have a conduction voltage of about 0.7 V
  - have a breakdown voltage that depends on their construction
    - perhaps 75 V for a **small-signal diode**
    - perhaps 400 V for a **power device**
  - have a maximum current that depends on their construction
    - perhaps 100 mA for a **small-signal diode**
    - perhaps many amps for a **power device**

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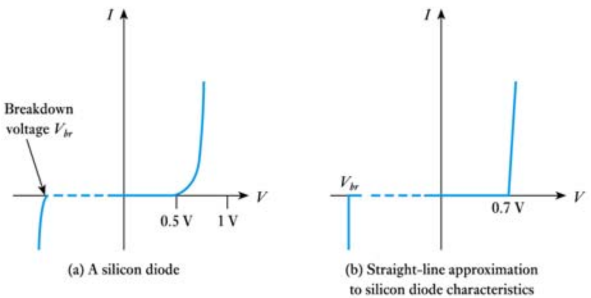
- **Turn-on** and **breakdown voltages** for a silicon device



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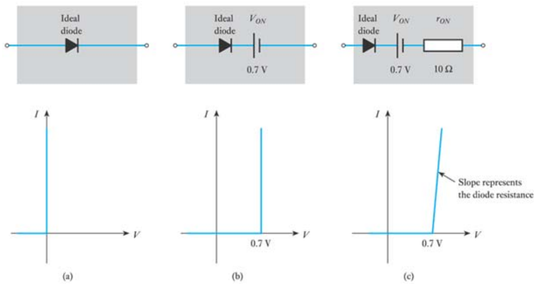
Diode equivalent circuits

- Sometimes we represent a diode by an equivalent circuit. Models have different levels of sophistication



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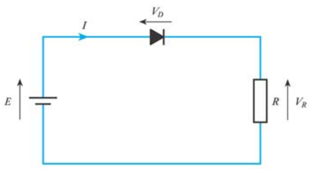
Diode circuit analysis

- The non-linear behaviour of diodes makes analysis difficult – consider this simple circuit



Applying Kirchoff's voltage law

$$E = V_D + V_R$$
$$= V_D + IR$$

From the diode equation

$$I = I_S(\exp 40V_D)$$

To find I we need to solve these two simultaneous equations

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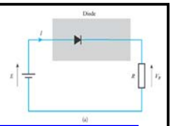
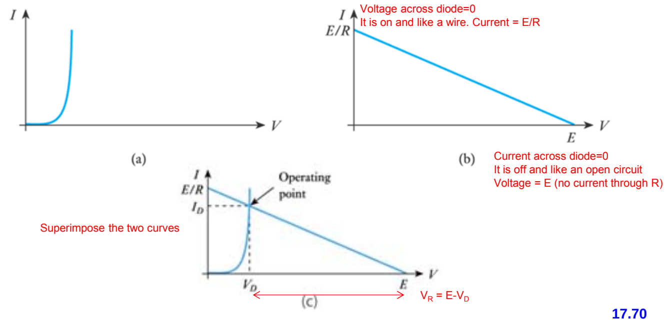


- One approach is through the use of a **load line**



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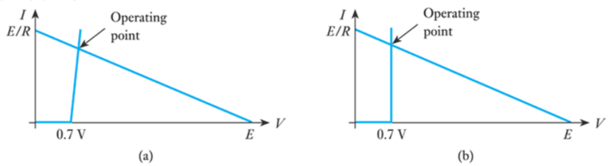
– Load lines can also be used with equivalent circuits…



…however, this is rarely done, since if an equivalent circuit is used, the circuit can normally be analysed directly, without resorting to a graphical method

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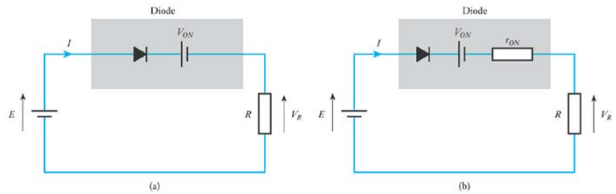

$$I = \frac{E - V_{ON}}{R}$$

$$I = \frac{E - V_{ON}}{R + r_{ON}}$$

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Effects of temperature

- Earlier we noted that

$$I \approx I_S\left(\exp\frac{eV}{kT} - 1\right)$$

  – for a given *I*, the voltage is inversely proportional to *T*
  – for a silicon diode, *V* decreases by about 2 mV per °C

  – the diode current is also affected by the reverse saturation current, which increases with temperature
  – I_S increases by about 7% per °C

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Reverse breakdown

- Can be caused by two mechanisms:
- **Zener breakdown**
  – in devices with heavily doped *p*- and *n*-type regions the transition from one to the other is very abrupt
  – this produces a very high field strength across the junction that can pull electrons from their covalent bonds.
  – produces a large reverse current
  – breakdown voltage is largely constant
  – Zener breakdown normally occurs below 5 V

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- **Avalanche breakdown**
  – occurs in diodes with more lightly doped materials
  – field strength across junction is insufficient to pull electrons from their atoms, but is sufficient to accelerate the electrons within the depletion layer
  – they loose energy by colliding with atoms
  – if they have sufficient energy they can liberate other electrons, leading to an avalanche effect
  – usually occurs at voltages above 5 V

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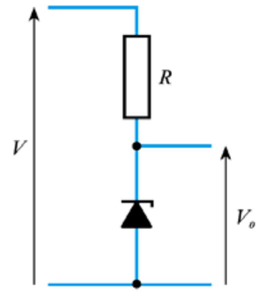
Special-purpose diodes

Too much current will kill diode

17.7

- **Zener diodes**
  – uses the relatively constant reverse breakdown voltage to produce a voltage reference
  – breakdown voltage is called the **Zener voltage**, V_Z
  – output voltage of circuit shown is equal to V_Z despite variations in input voltage *V*
  – a resistor is used to limit the current in the diode



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- **Schottky diodes**
  - formed by the junction between a layer of metal (e.g. aluminium) and a semiconductor
  - action relies only on majority charge carriers
  - much faster in operation than a *pn* junction diode
    - Don't have to wait for recombination of minority carriers
  - has a low forward voltage drop of about 0.25 V
  - used in the design of high-speed logic gates

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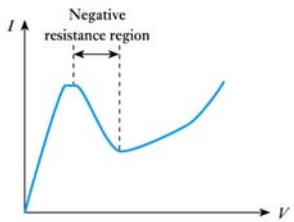
- **Tunnel diodes**
  - high doping levels produce a very thin depletion layer which permits 'tunnelling' of charge carriers
  - results in a characteristic with a **negative resistance** region
  - used in high-frequency oscillators, where they can be used to 'cancel out' resistance in passive components



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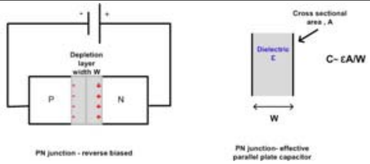
Extra Large depletion region



- **Varactor diodes**
  - a reversed-biased diode looks like two conducting regions separated by a large insulating depletion region
  - this structure resembles a capacitor
  - variations in the reverse-bias voltage change the width of the depletion layer and hence the capacitance
  - this produces a **voltage-dependent capacitor**
  - these are used in applications such as **automatic tuning circuits**

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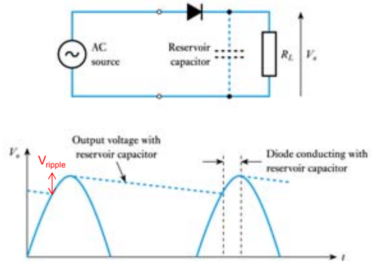
Diode circuits

Video 17A 17.8

- **Half-wave rectifier**
  - peak output voltage is equal to the peak input voltage minus the conduction voltage of the diode
  - reservoir capacitor used to produce a steadier output



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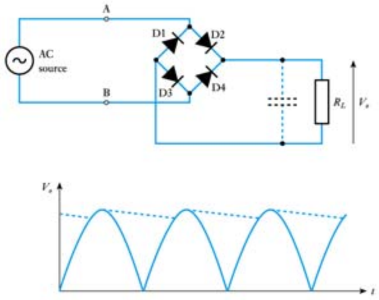
- **Full-wave rectifier**
  - use of a diode bridge reduces the time for which the capacitor has to maintain the output voltage and thus reduce the ripple voltage



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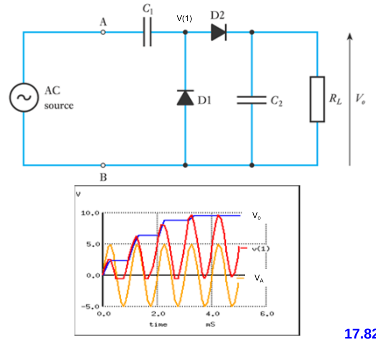
- **Voltage doubler**
  - charges C_2 to nearly twice the peak input voltage
  - several stages can be cascaded to produce very high voltages
  - ideal in applications requiring high voltages at low currents



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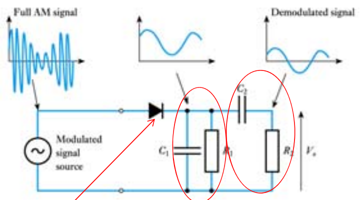
Video 17B

- **Signal rectifier**

Signal is the low frequency part
Carrier is the high frequency part

  - used to demodulate full amplitude modulated signals (**full-AM**)
  - also known as an **envelope detector**
  - found in a wide range of radio receivers from crystal sets to superheterodynes



Diode half-wave rectifies the signal (no negative voltages)

Low pass filter
$\omega_c = R_1 \cdot C_1 > \omega_s$ but less than carrier frequency
Removes carrier frequency

High pass filter removes DC

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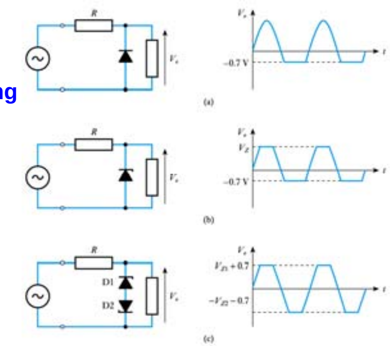
- **Signal clamping**
  - a simple form of **signal conditioning**
  - circuits limit the excursion of the voltage waveform
  - can use a combination of signal and Zener diodes



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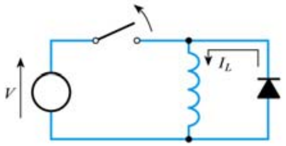
- **Catch diode**
  - used when switching inductive loads
  - the large back e.m.f. can cause problems such as arcing in switches
  - **catch diodes** provide a low impedance path across the inductor to dissipate the stored energy
  - the applied voltage reverse-biases the diode, which therefore has no effect
  - when the voltage is removed the back e.m.f. forward biases the diode which then conducts



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Further Study

Video 17C

Further Study

- The Further Study section at the end of Chapter 17 is concerned with the design of a mains power supply.
- The supply is to drive an appliance that requires a fairly constant input of 12V and takes a current that varies from 100 to 200 mA.
- Design such a unit and then look at the video.

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Key points

- Diodes allow current to flow in only one direction
- At low temperatures semiconductors act like insulators
- At higher temperatures they begin to conduct
- Doping of semiconductors leads to the production of *p*-type and *n*-type materials
- A junction between *p*-type and *n*-type semiconductors has the properties of a diode
- Silicon semiconductor diodes approximate the behaviour of ideal diodes but have a conduction voltage of about 0.7 V
- There are also a wide range of special purpose diodes
- Diodes are used in a range of applications

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