Module 5

Active Devices and Power Supplies

References

- *Canadian Amateur Radio Basic Qualification Study Guide* (8th Ed.), Chapters 9 and 10

Active Devices

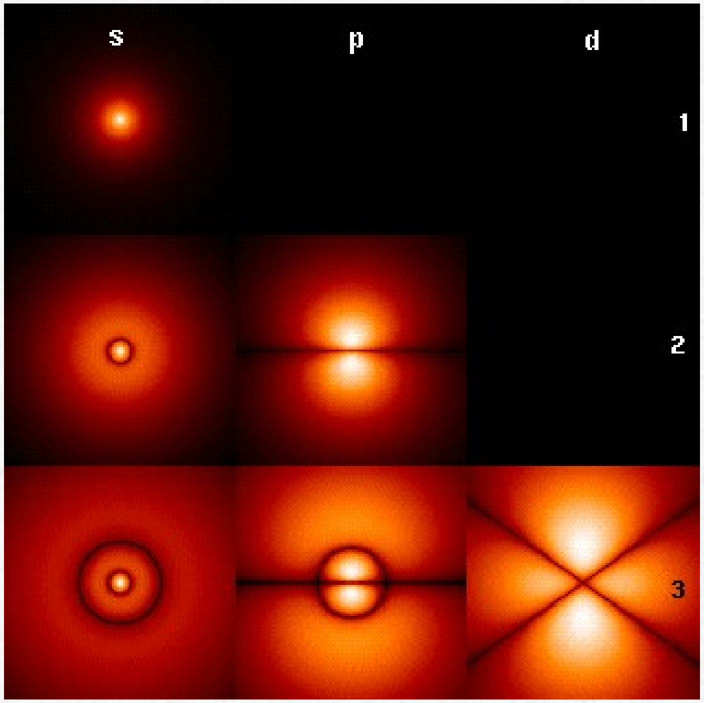
Diodes, Transistors and Tubes

Introduction

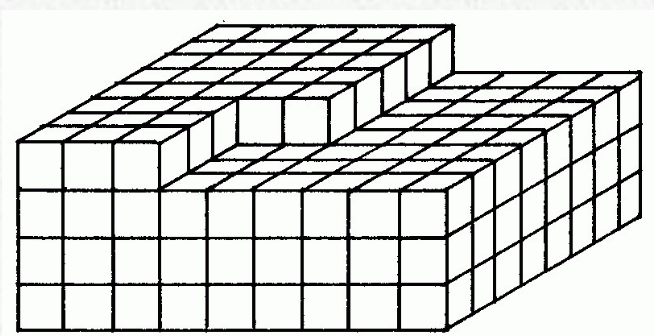
- conductors
- insulators
- semi-conductors
- purpose of electronics is to control the flow of current in one way or another so that intelligence can be impressed upon the current flow, modified as desired and recovered at a distant location

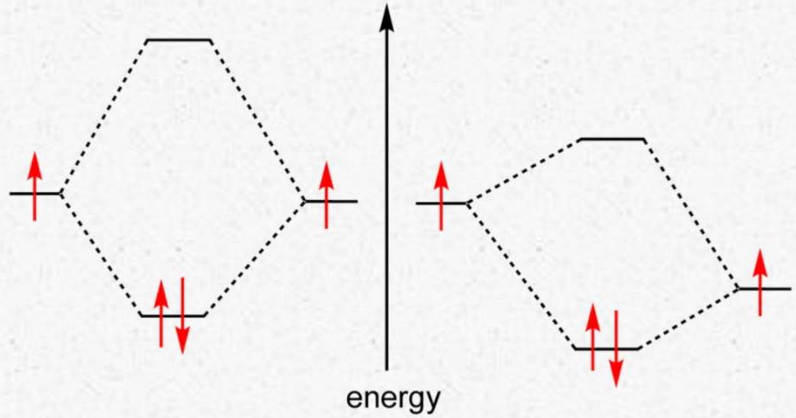
Semiconductors

- conductors – valence or outer shell electrons not tightly bound to nucleus and and can be displaced by other electrons
  - become part of electric current flowing
  - these are electron carriers
- semiconductor
  - material packed together in crystal lattice
  - interaction of nearby electron clouds gives rise to covalent bonding

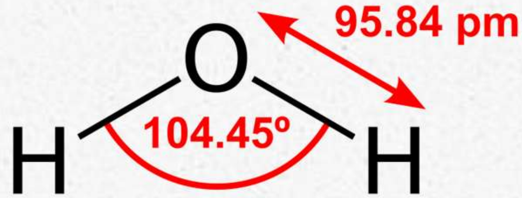


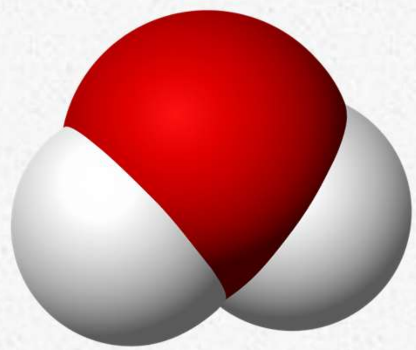
First Few Hydrogen Orbitals





Covalent Bonding between Molecules



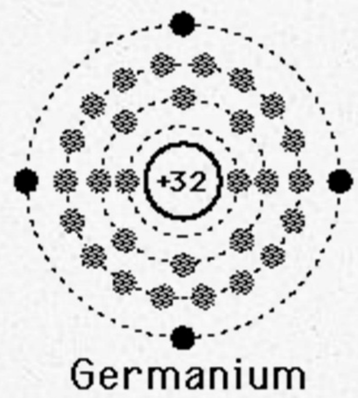


Semiconductors

- What is a poor conductor (Si) in crystal state suddenly becomes a good conductor
- impurity must be introduced with one more (5) or one fewer (3) valence electrons
- stability of crystal undermined – doping/dopant
- doped semiconductor crystal can now carry electrical current more easily due to imbalance
- if one more then charge carriers are electrons
- if one less then charge carriers are holes
- if undoped = intrinsic semiconductor
- if doped = extrinsic semiconductor

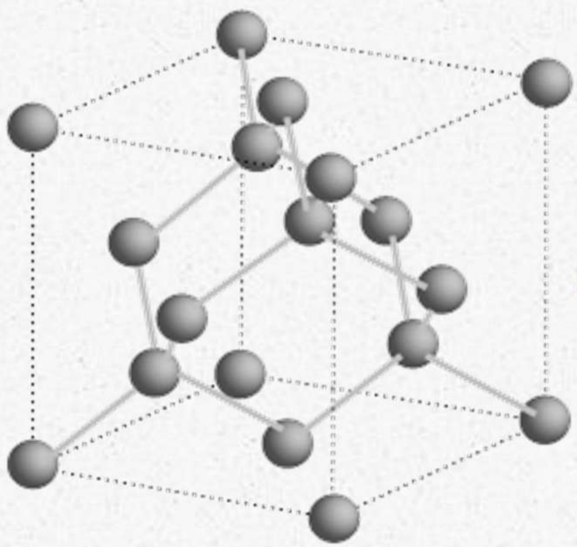
Semiconductors

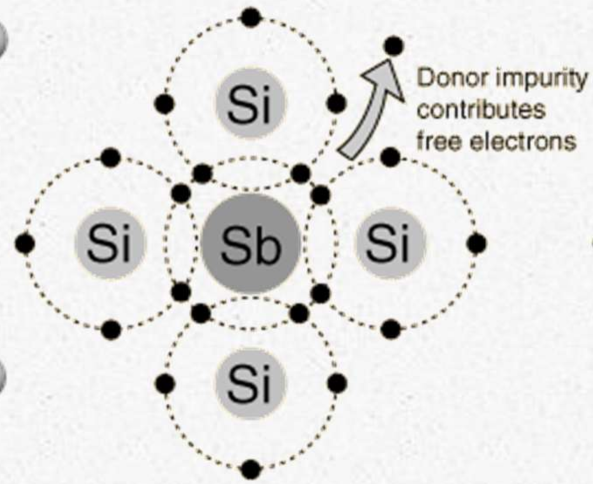
- N-type – extra valence electron (-ve) – electron is primary charge carrier
- P-type – missing valence electron (+ve) – hole is the major charge carrier
- Si (+4); Ge (+4); GaAs

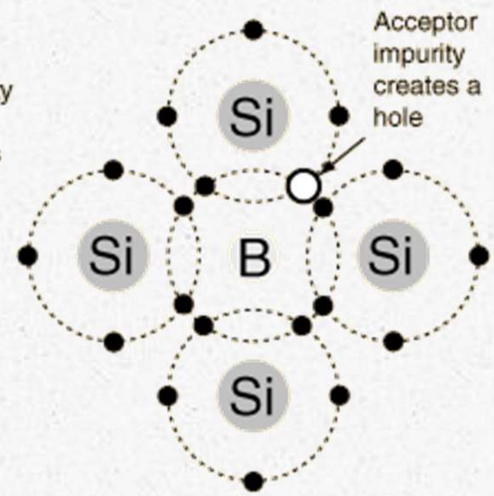


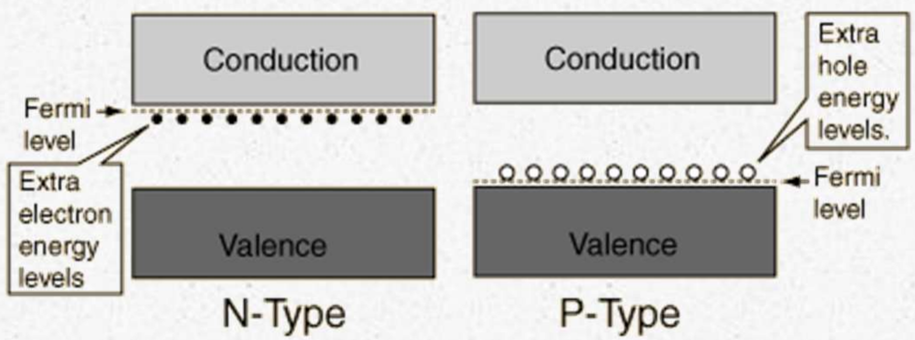
Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



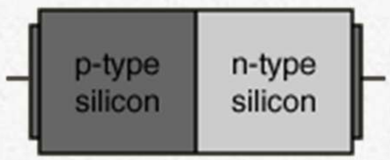

Si
Si
Sb
Si
Si
Donor impurity
contributes
free electrons


Acceptor
impurity
creates a
hole
Si
Si
B
Si
Si

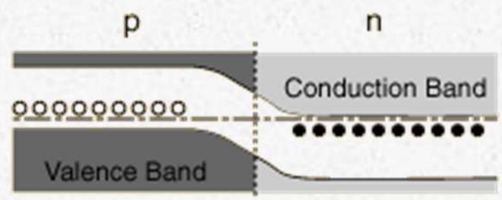

Conduction
Fermi
level
Extra
electron
energy
levels
Valence
N-Type
Conduction
Extra
hole
energy
levels.
Fermi
level
Valence
P-Type

Junctions

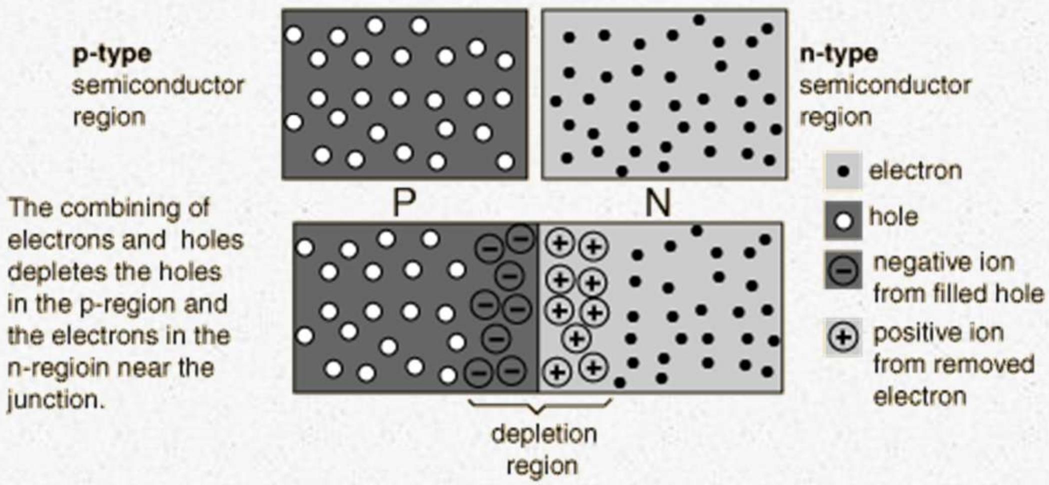
- If an N-type material placed close contact to a P-type material we get a PN junction
  - N-type material is an area of –ve polarity – a cathode
  - P-type material is an area of +ve polarity – an anode
  - some electrons diffuse across boundary with no applied voltage – barrier layer or depletion zone

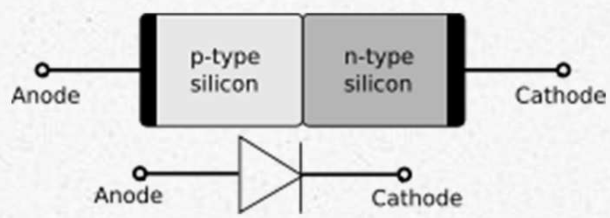


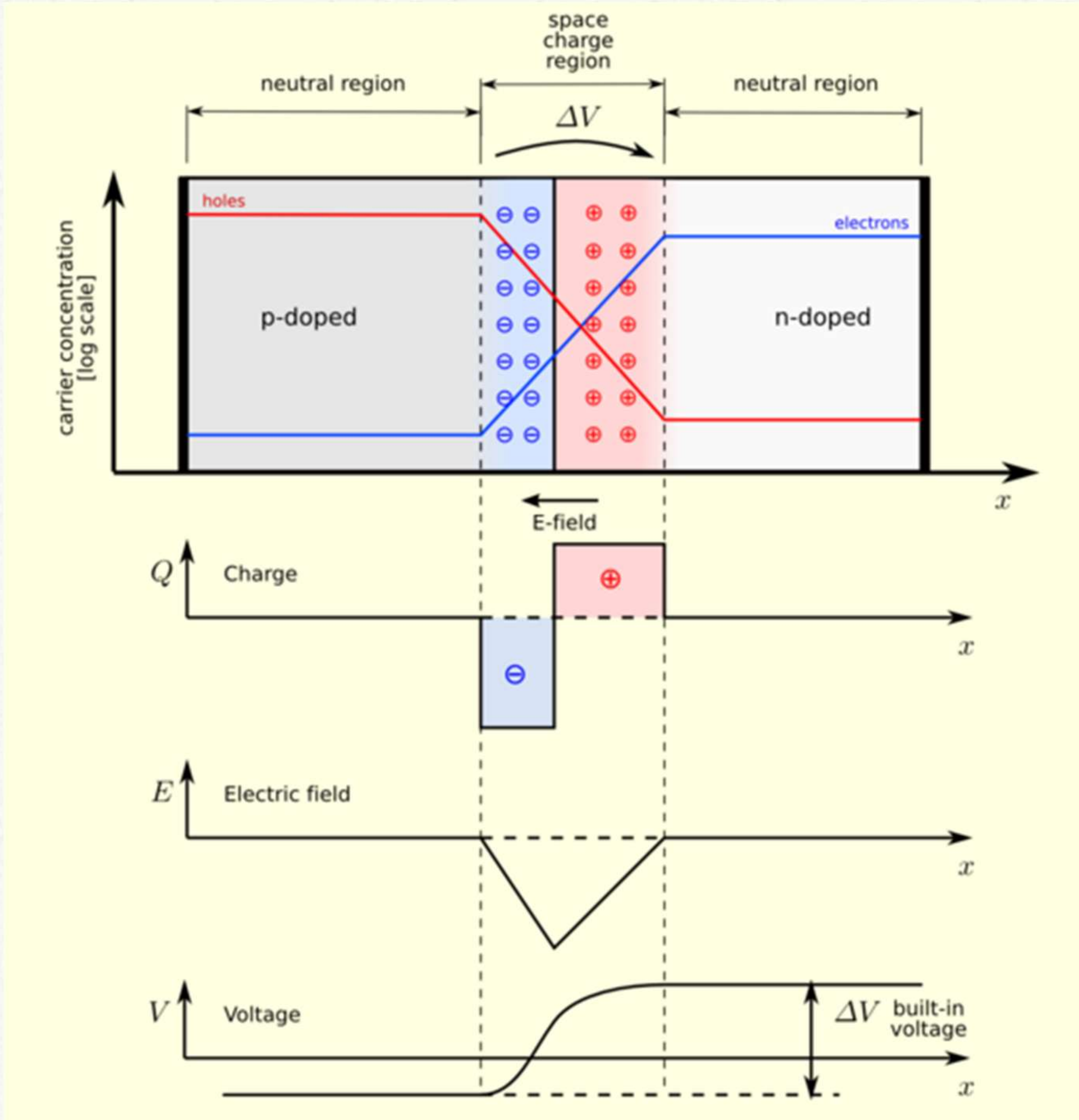
p-n junction



Energy bands at equilibrium







space charge region
neutral region
neutral region
ΔV
holes
electrons
p-doped
n-doped
carrier concentration [log scale]
x
E-field
Q
Charge
x
E
Electric field
x
V
Voltage
ΔV built-in voltage
x

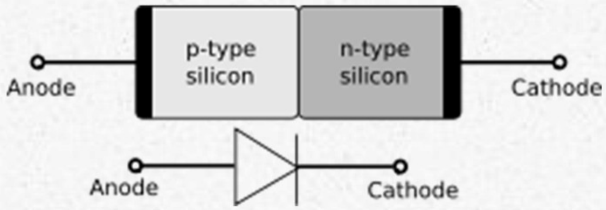
Junctions

- When battery connected so that +ve connected to P-type material (anode) and –ve connected to N-type material (cathode), current flows easily
- depletion zone removed
- this is called forward biasing
- forward bias voltage is V applied

Junctions

- If battery connected so that N-type material is at the +ve end of battery and P-type at –ve end, then battery adds to barrier potential and only a small current (leakage current) flows
- reverse biased
- reverse bias voltage

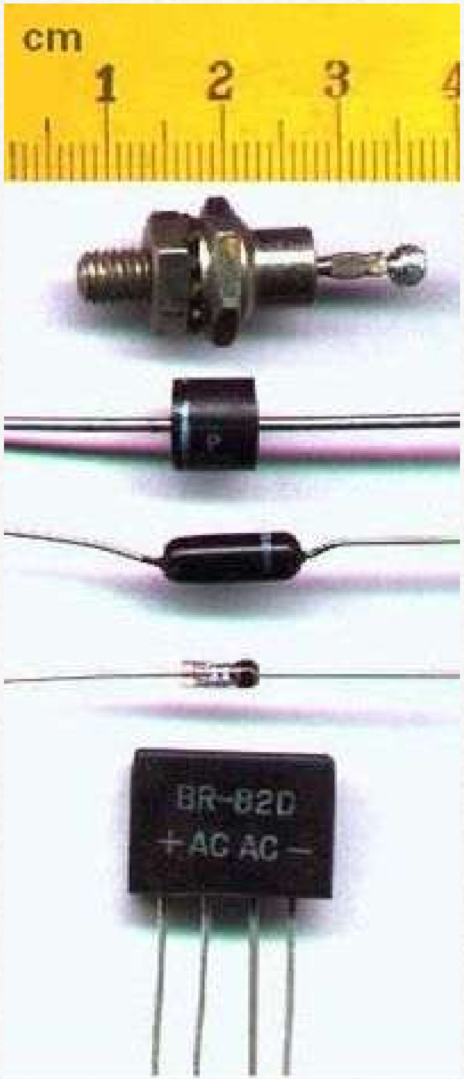
Diode

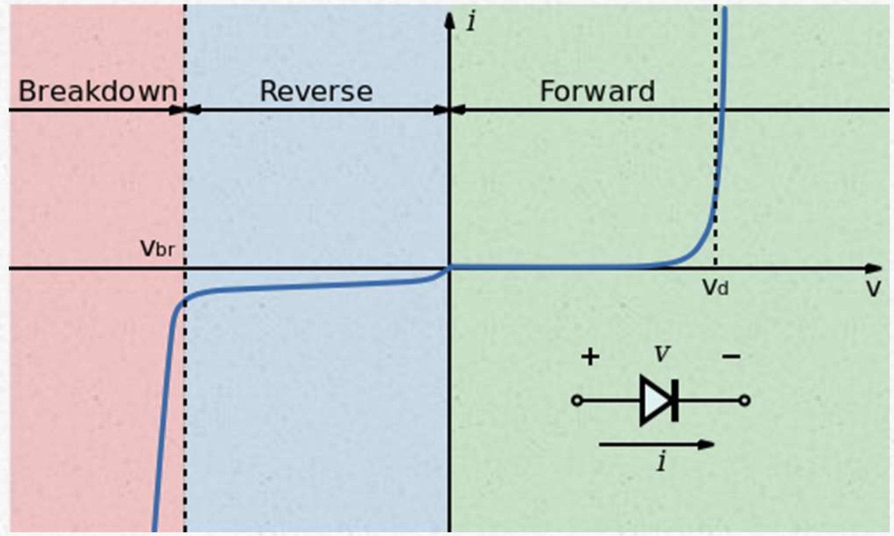


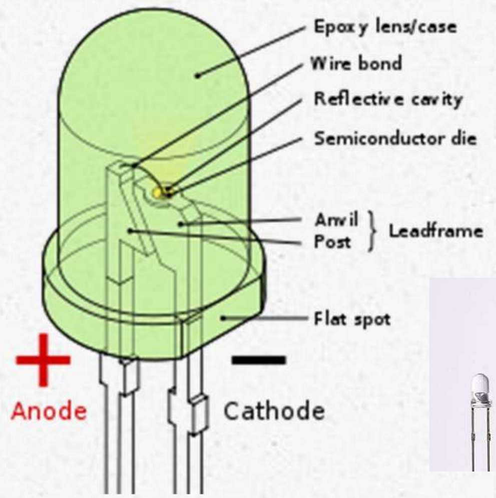
- This device is a diode
- Note the arrowhead
- current flows only in one direction
- when current flows in other direction, it is generally blocked
- If reverse bias voltage too high, diode will fail

Diodes

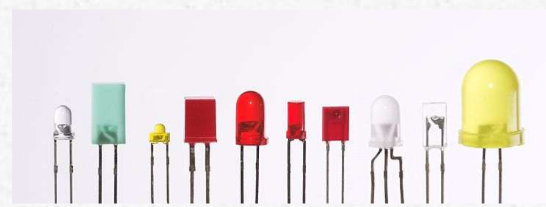
- Zener diode – keeps voltages steady in power supplies – functions as a voltage regulator
- Varactor diode – solid state replacement for large tuning capacitors – changes capacitance as voltage changes across the PN junction
- Light Emitting Diode (LED) – Red, yellow, green, blue or white light when forward biased (lasers)


cm
1 2 3 4
BR-82D
+AC AC −


Breakdown
Reverse
Forward
i
Vbr
Vd
V
+ v −
i


Epoxy lens/case
Wire bond
Reflective cavity
Semiconductor die
Anvil
Post
Leadframe
Flat spot
+
Anode
−
Cathode


Anode
Cathode

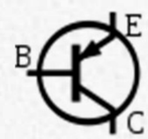



-1.4142136

Transistor

- How to control current in circuit?
  - switch current on and off
  - control current continuously variable manner like a tap controls flow of water
- Transistor = transfer resistor

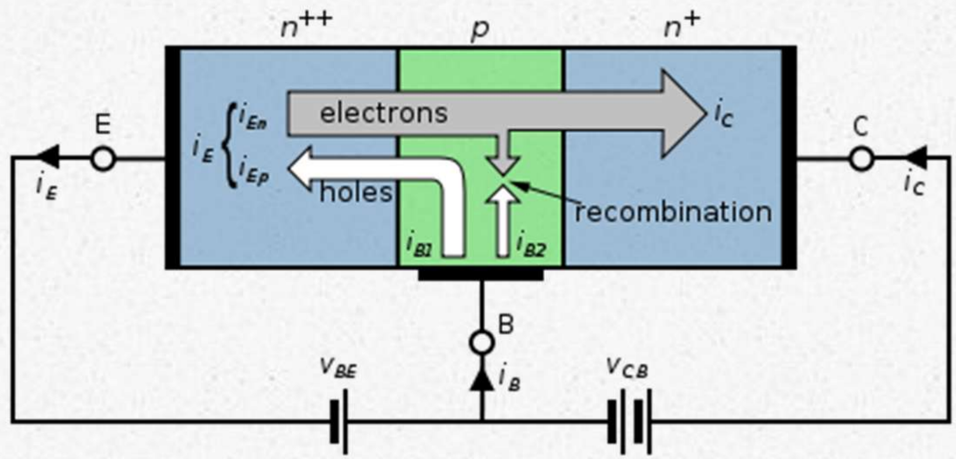
PNP



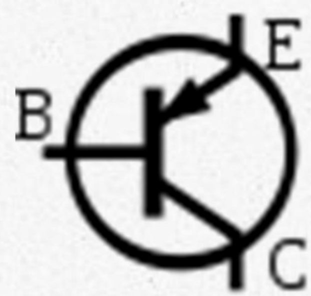
NPN

NPN Transisor

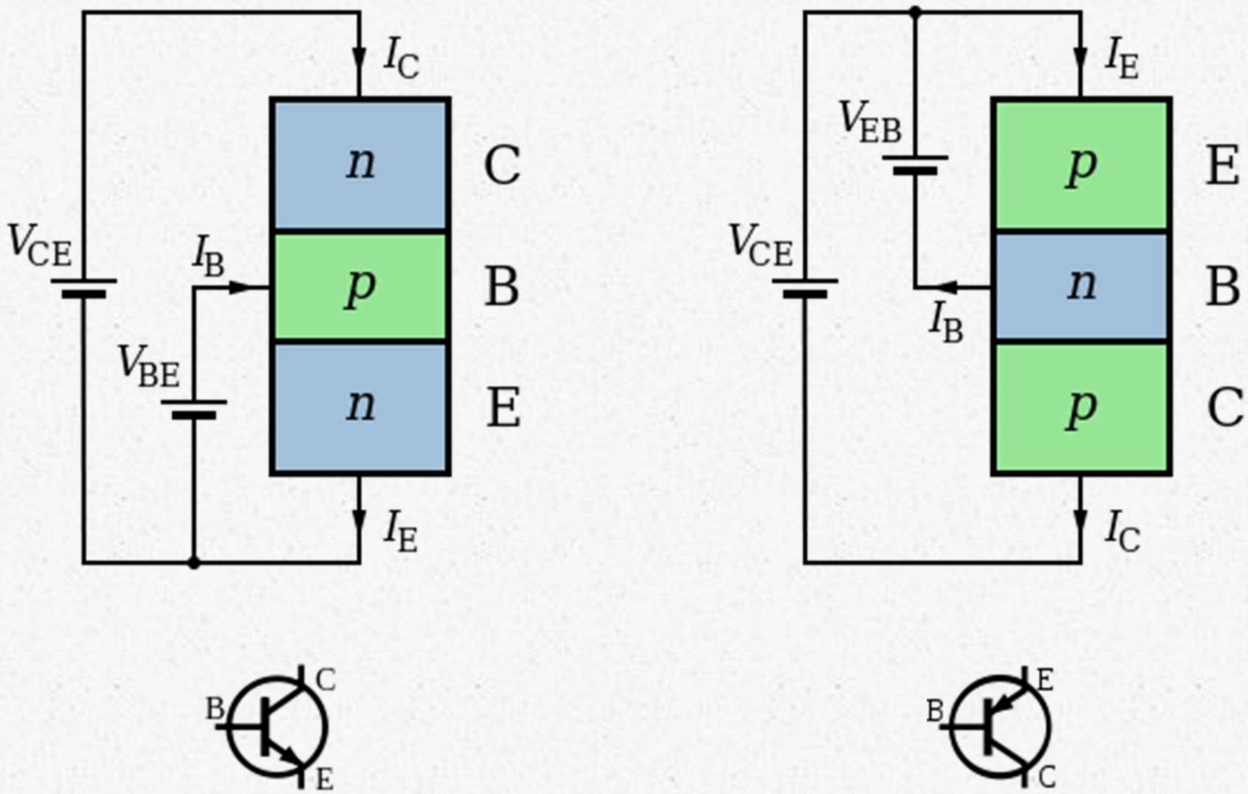
- B – Base
- C – Collector
- E – Emitter



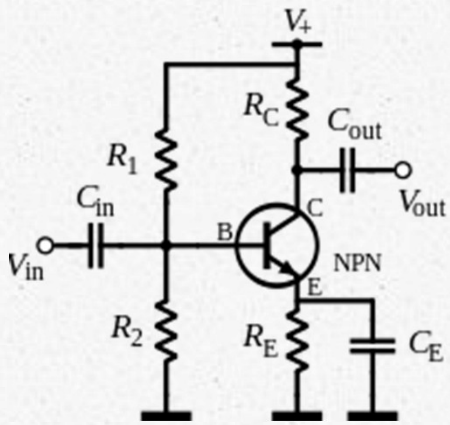
Base is forward biased
Small amount of current from E to the Base controls large current flowing from E through the B to the C



Bipolar Transistors

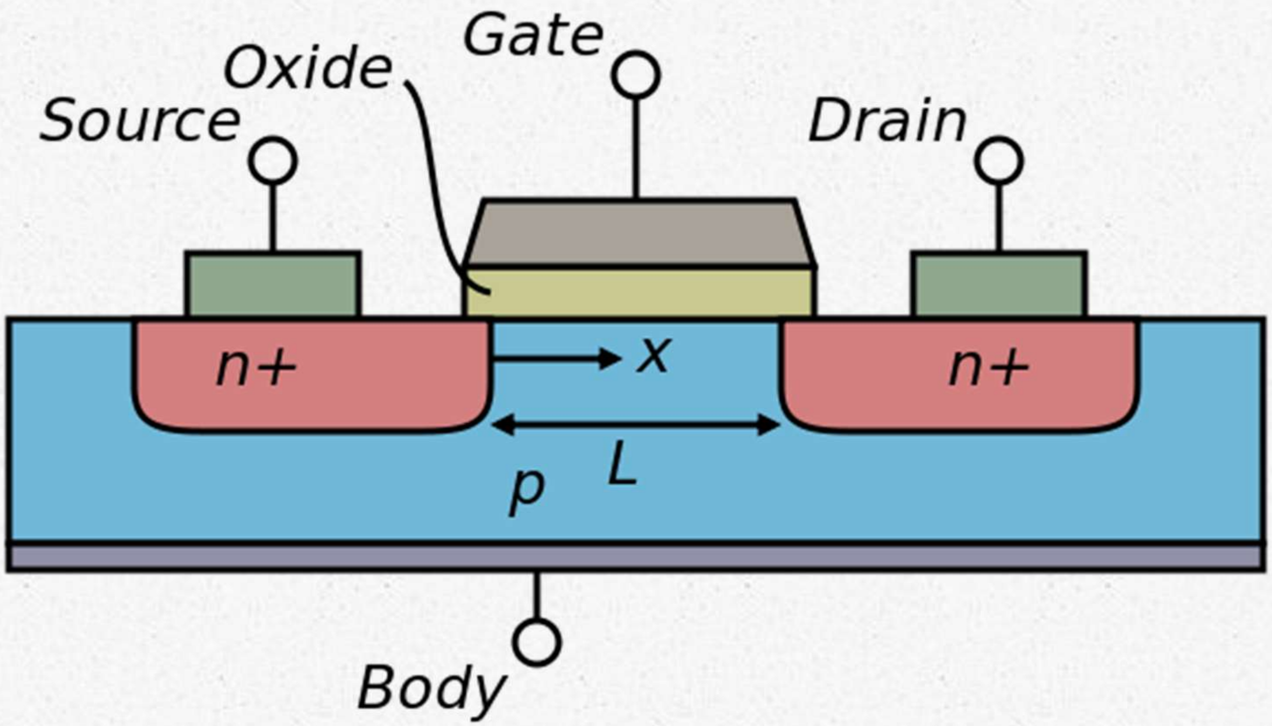


Transistors



Field Effect Transistor

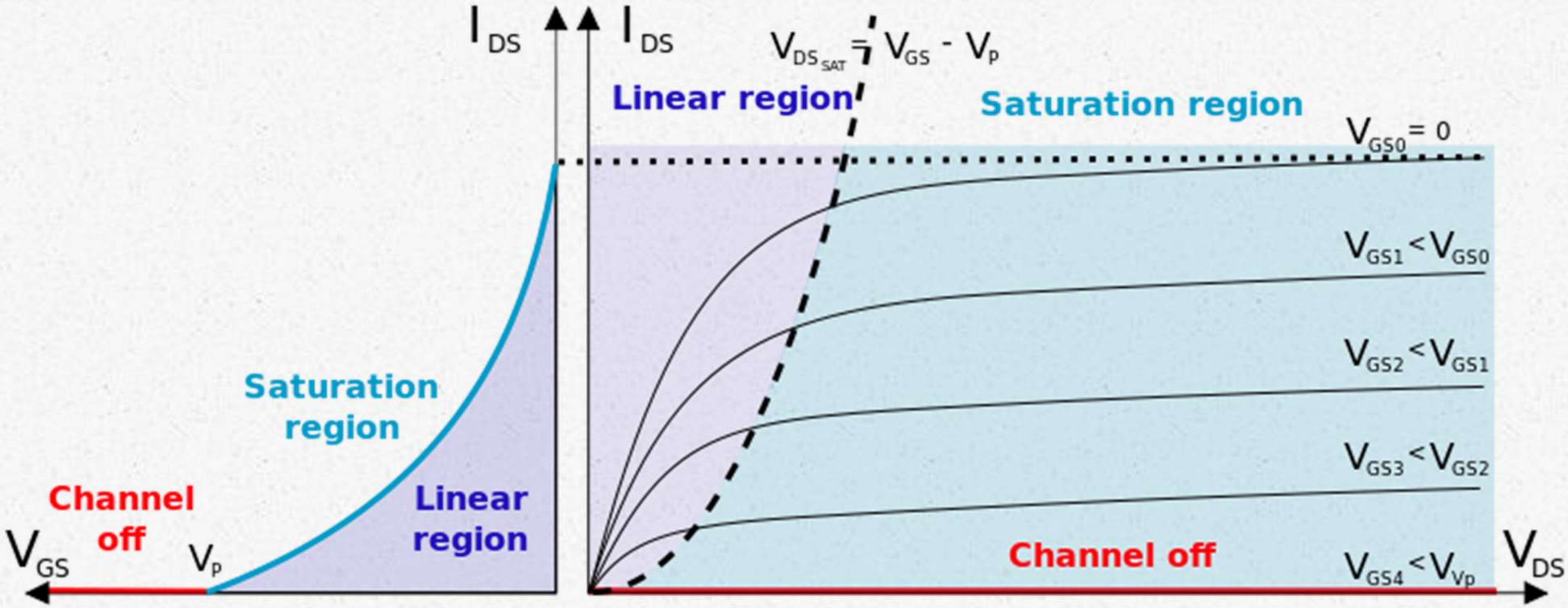
- FET



FET

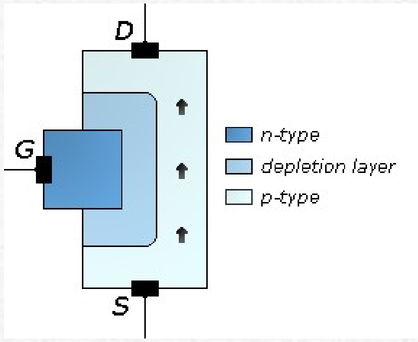
- Increasing reverse bias reduces current flow; decreasing the reverse bias voltage increases current flow
- A small voltage can control a relatively large current
- A large enough voltage will cut off current entirely – Pinch-off voltage
- Little or no current flows in control gae of FET and it has high impedance
- FET does not cause DC loading on preceding parts of circuit

FET



I_{DS}
I_{DS}
$V_{DS_{SAT}} = V_{GS} - V_P$
Linear region
Saturation region
$V_{GS0} = 0$
$V_{GS1} < V_{GS0}$
$V_{GS2} < V_{GS1}$
$V_{GS3} < V_{GS2}$
$V_{GS4} < V_{Vp}$
Saturation region
Linear region
Channel off
Channel off
V_{GS}
V_P
V_{DS}

JFET

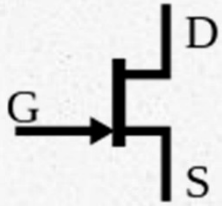


- The junction gate field-effect transistor (JFET or JUGFET) is the simplest type of field-effect transistor. It can be used as an electronically-controlled switch or as a voltage-controlled resistance. Electric charge flows through a semiconducting channel between "source" and "drain" terminals. By applying a reverse bias voltage to a "gate" terminal, the channel is "pinched", so that the electric current is impeded or switched off completely.

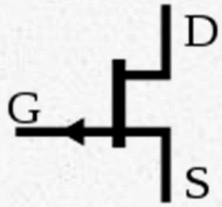
JFET

- Like a garden hose. Flow controlled by squeezing it to reduce cross section.
- Source – point at which charge carriers enter channel (corresponds to Emitter)
- Drain – terminal where charge carriers leave channel (corresponds to Collector)
- Gate – electrode controls conductance of channel between source and gate (corresponds to Base) – gate voltage controls field in channel (in BPT it controls current)

N Channel



P Channel



Gain

- Increased power in signal by electronic means = amplification (amplifier)
- Amplifies V, I or P
- Note transistors can be used in other things, including oscillator circuits

Gain

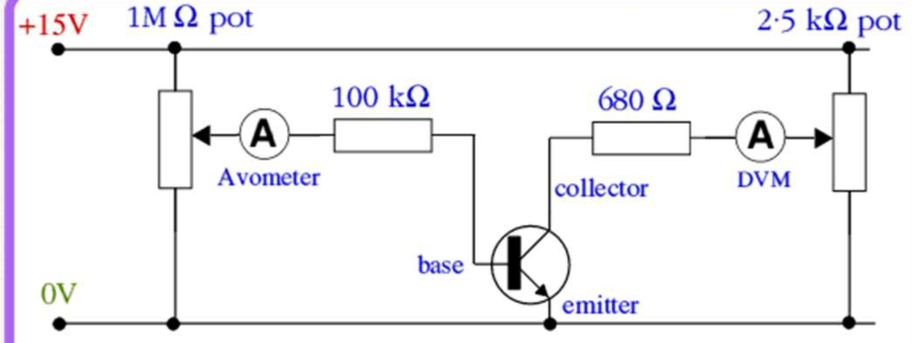


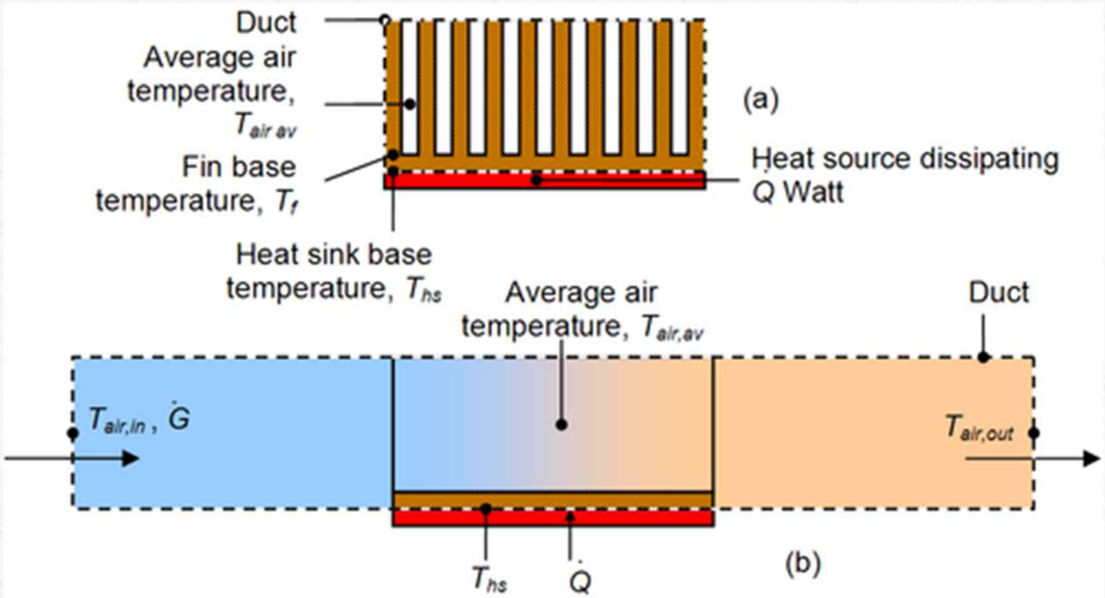
Diagram 5. Arrangement for measuring transistor properties.

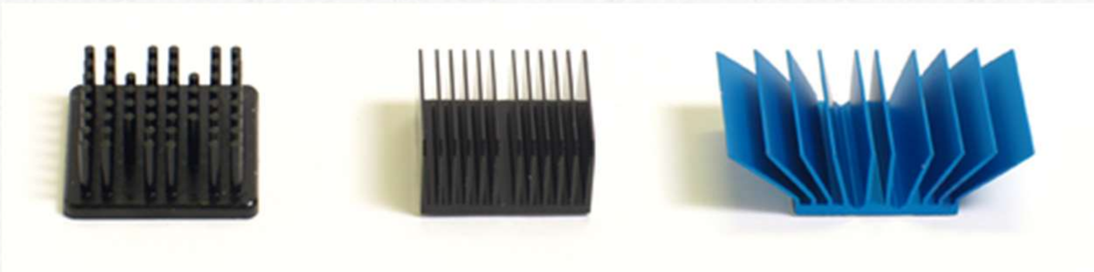
- Common emitter
- Collector resistor
  - supplies operating power and resistance to obtain output signal voltage
- AF amplifiers (20 Hz to 20 kHz)
- RF amplifiers

Transistor Characteristics

- Breakdown Voltage – max voltage applied between electrodes
- Maximum Voltage – max operating voltage between any two electrodes - < breakdown voltage
- Maximum Current – Most important is max collector current I_C
- Maximum Power – Max power where heat does not destroy resistor – current flow very dependent on heat – thermal runaway

Heat Sinks


Duct
Average air temperature, $T_{air\ av}$
Fin base temperature, T_f
(a)
Heat source dissipating Q Watt
Heat sink base temperature, T_{hs}
Average air temperature, $T_{air,av}$
Duct
$T_{air,in}$, $\dot{G}$
$T_{air,out}$
T_{hs}
$\dot{Q}$
(b)

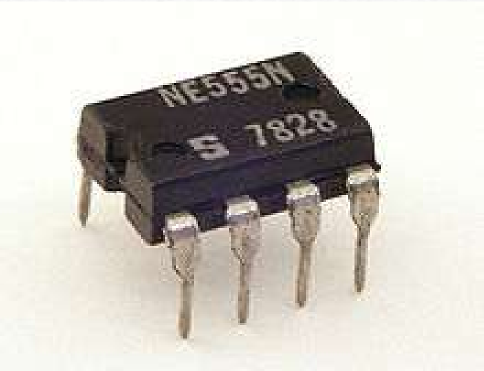


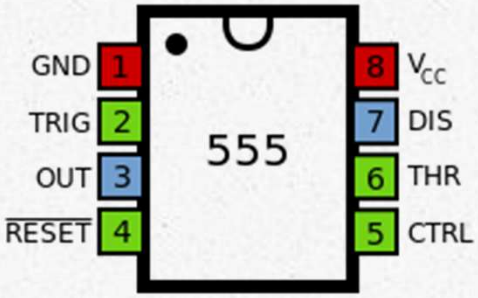
Integrated Circuits

- An integrated circuit or monolithic integrated circuit (also referred to as IC, chip, or microchip) is an electronic circuit manufactured by lithography, or the patterned diffusion of trace elements into the surface of a thin substrate of semiconductor material. Additional materials are deposited and patterned to form interconnections between semiconductor devices.

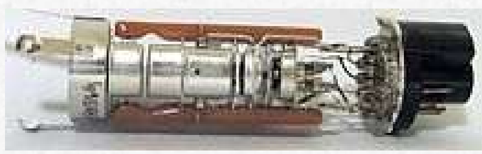
Integrated Circuits

- Scale – very small
- single substrate – material on which constructed – ensures uniformity of characteristics over range of temperature and voltage – high specification
- reliability –
- cost –
- dual inline

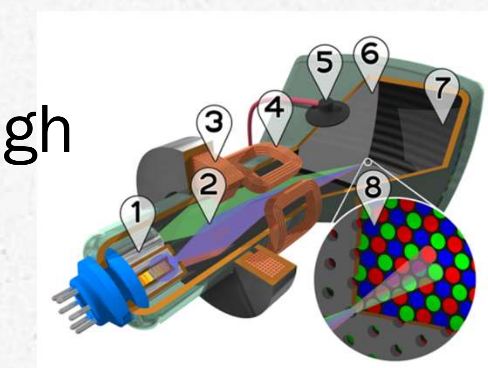




Vacuum Tubes

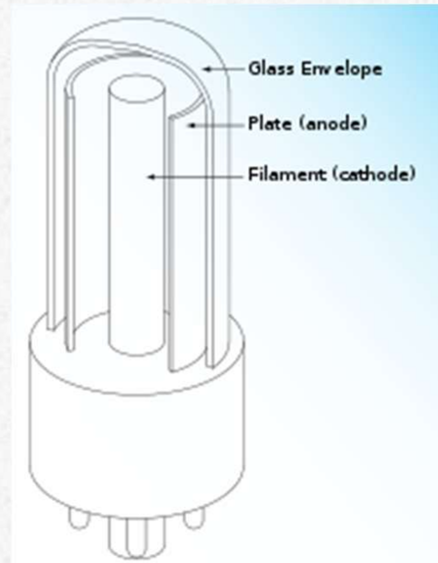


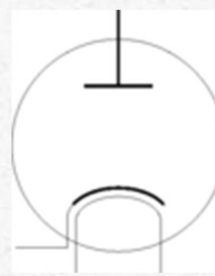
- generally precursor to semiconductors
- antiques
- still in use in some equipment (high performance)



Vacuum Diode

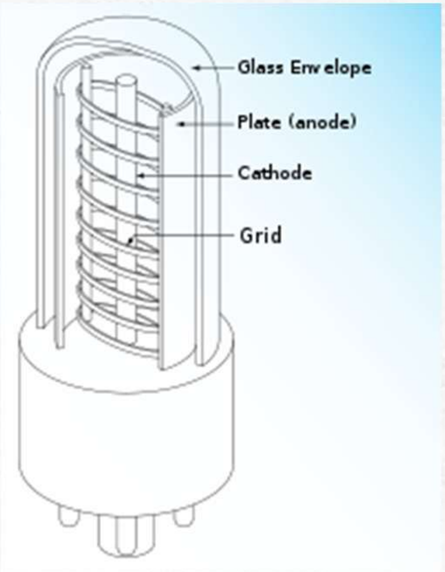
- filament
- metal or glass shell (vacuum)
- filament releases electrons into vacuum (thermionic emission)
- Anode or plate attracts those electrons (+ve)
- flow is in one direction
- DIODE
- rectification (AC to DC); DC power supplie, AM demodulator etc.

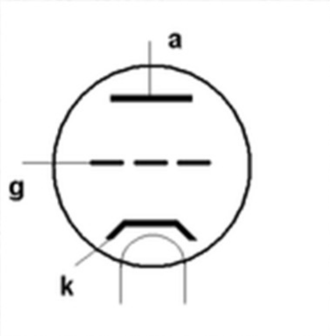




Vacuum Triode

- Third electrode – screen mesh – Grid
- Like a diode but small amount of electrons will strike grid – if grid made –ve then we can prevent electrons from striking grid wires and prevent current flowing
- cut-off, grid bias, grid voltage, cut-off bias
- similar effect to the FET
- very common in very high power applications

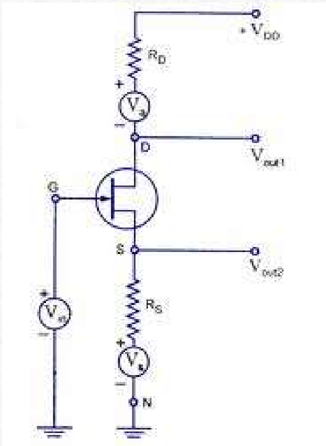




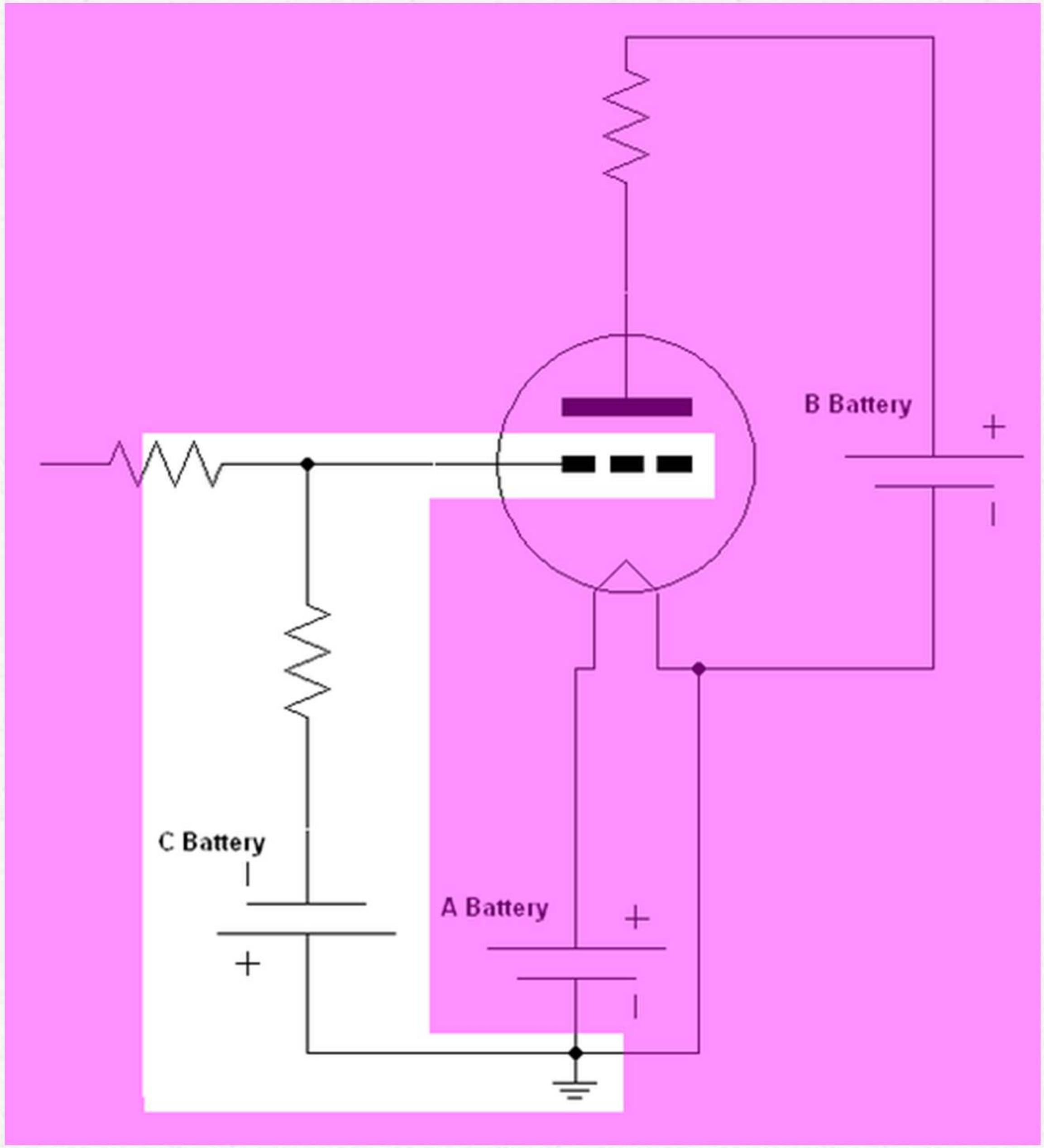
Comparison

	Transistor (NPN)	FET (N Channel)	Triode
Input	Emitter	Source	Cathode
Output	Collector	Drain	Plate/Anode
Control	Base	Gate	Control Grid

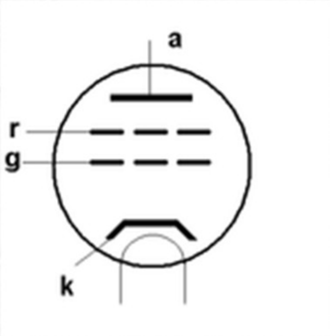
*No analogue to PNP or P Channel in tubes/valves



A Generalized FET Amplifier



Multi-Electrode Tubes



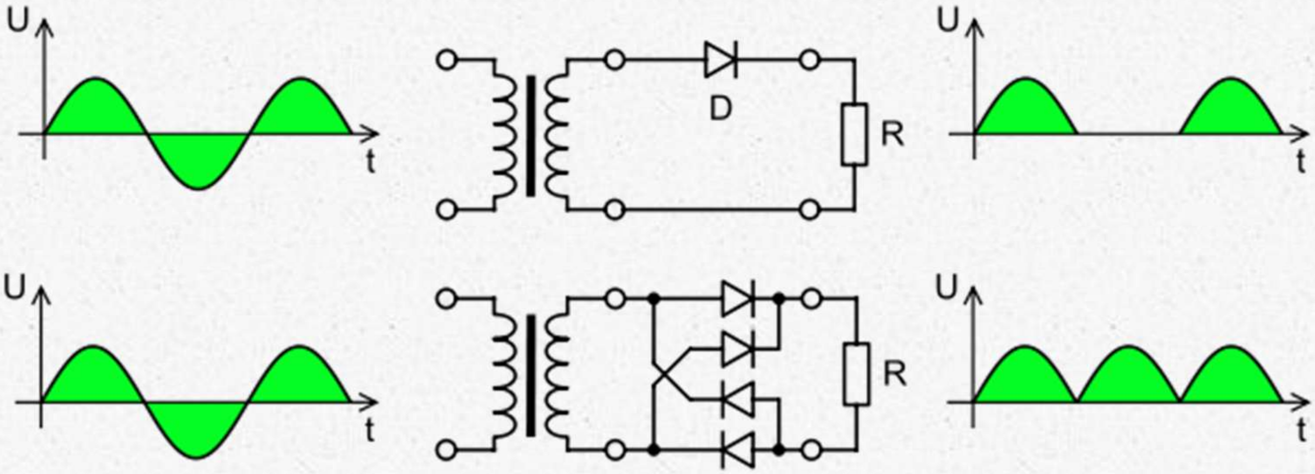
- Tetrodes and Pentodes (1919)
- Tetrode
  - Second screen grid overcomes
    - capacitance between grid and plate
    - amplification (feedback) problem
  - higher gain
- Pentode
  - Third screen (suppressor grid)
  - Even greater gain (100 times more than tetrode)

Power Supplies

Chapter 10

Power Requirements

- Batteries
- Often plug into 120 V AC outlet
  - Voltage often lowered or raised (e.g. 13.8 V)
  - Voltage needs to be changed to DC



Power Requirements

- Ripple – caused by changing AC to pulsating DC
- DC must be filtered to remove ripple
  - regulation
  - DC voltage must remain at a fairly constant value
- Power Supply

Power Supply

- Design factors
  - Input Voltage (what is the input AC voltage)
  - Output Voltage (higher or lower)
  - Rectification (AC to DC)
  - Filtering (get rid of ripple)
  - Output Current (how much?)
  - Voltage Regulation (what limits)

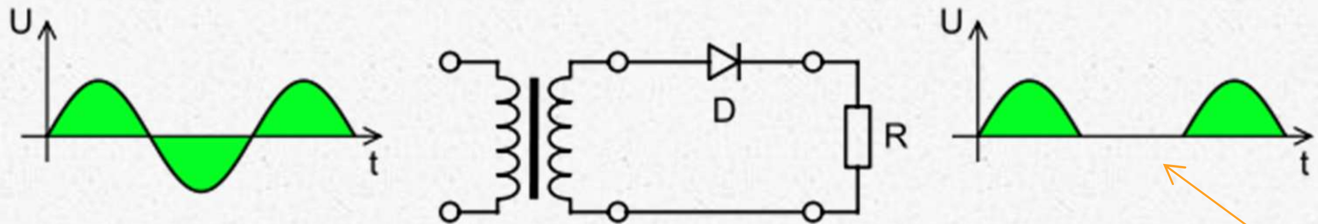
Power Supply

- See block diagram on p. 10-2
- protection from internal failure that might cause voltage to rise to high levels damaging equipment
- protection from accidental overload by current or voltage – breakers or fuses

Transformers

- recall $\frac{E_P}{E_S} = \frac{N_P}{N_S}$
- So if I have an input of 120 VAC and the primary consists of 240 turns, how many turns in the secondary to produce voltage of 20 VAC? 40 turns. Ratio of 6:1.
- Power rating of transformer
  - volt-amperes (VA)
  - If HF radio draws 20A when it transmits need a heavy duty power supply – lots of mass – due to windings
  - 20 A at 13.8 V is how many Watts? [276 W]
- Isolation

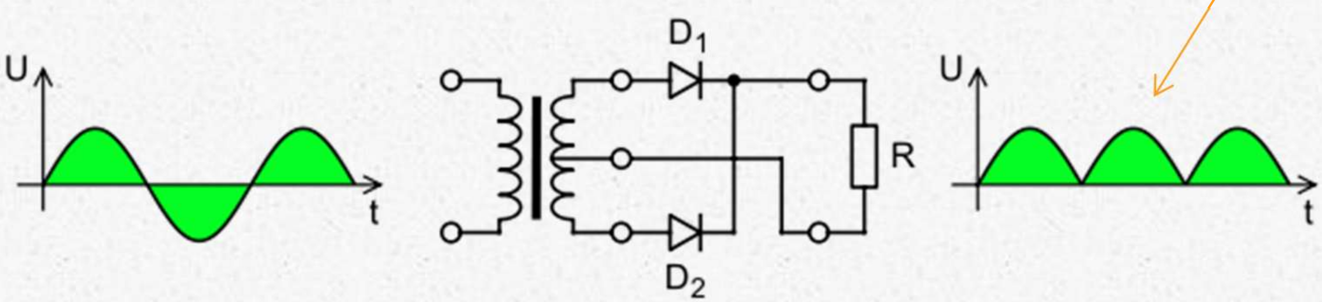
AC to DC



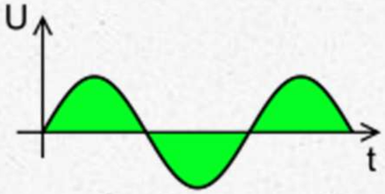
- rectification
- Si diodes
- half wave rectification v. full wave rectification

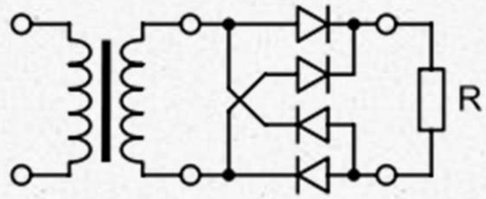
Filtered

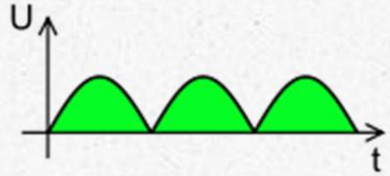
Inversion

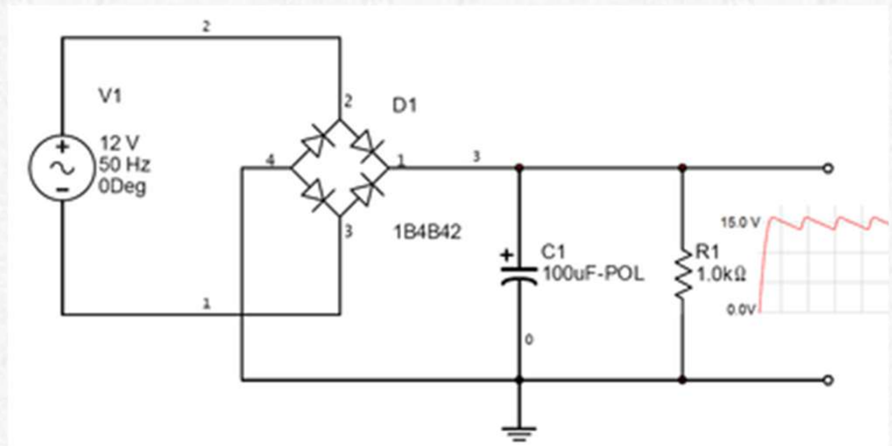


Full Wave Bridge Rectifier



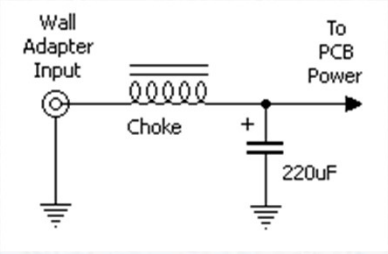






Filtering DC

- Need to smooth out the output from rectifier
- Ripple creates hum (BPL)
- next state is a filter circuit
- capacitor inserted in parallel to circuit
  - capacitor filtering/bleeder resistor
  - common in wall warts
- Adding an inductor to remove ignition noise
- AC hum
  - drying out of capacitor

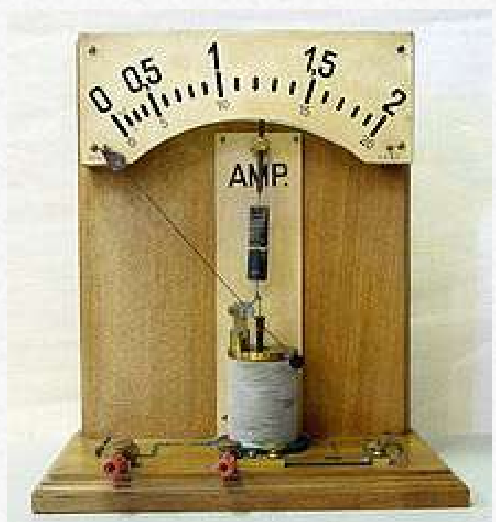


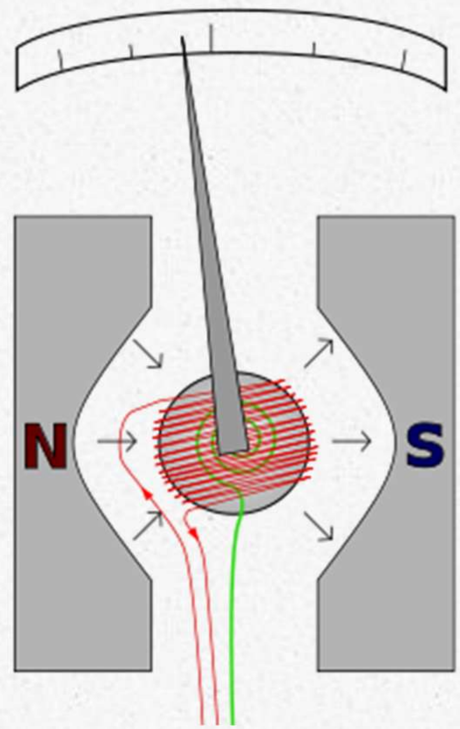
Regulating Voltage and Current

- filtered output is nearly pure DC
- slight drop in voltage in AC to DC
- as current increases, voltage drops (P=IV)
- regulator ensures voltage stays constant despite demand – controlled electronically with a variable resistor between filter and output
- power supplies rated for max current
- in CW operation, chirps

Monitoring Output

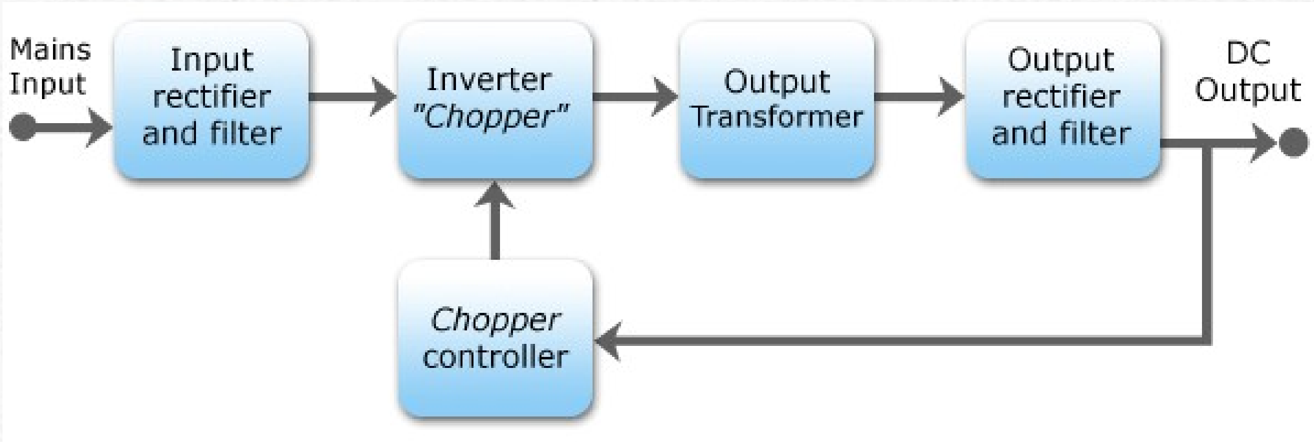
- Voltmeters – hooked up in parallel
- Ammeters – hooked up in series

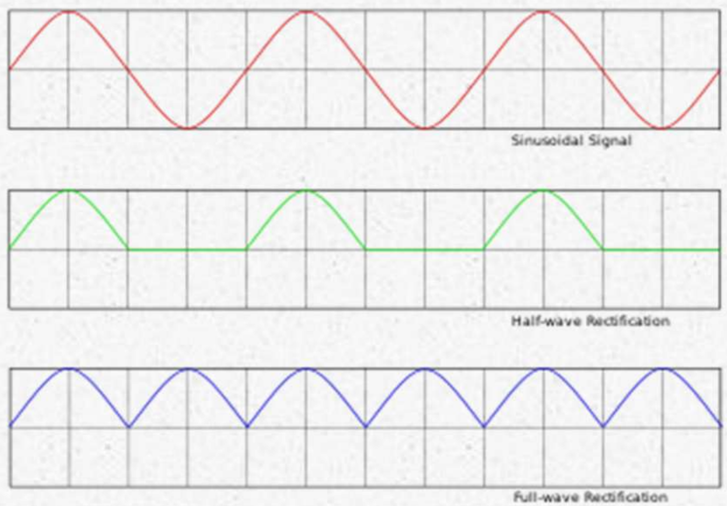




Switched Mode Power Supply

- Not on exam
- computer power supply
- solid state circuitry
- low loss
- smaller
- switching causes noise (filtering)


Mains Input
Input rectifier and filter
Inverter "Chopper"
Output Transformer
Output rectifier and filter
DC Output
Chopper controller


Sinusoidal Signal
Half-wave Rectification
Full-wave Rectification

Summary

- Active Devices
  - Diodes, transistors, FETs, Tubes (diodes, triodes and tetrodes)
- Power Supplies
  - Rectification
  - Filtering
  - Regulation
  - Monitoring of Output

Questions?

Demonstration