Unit 14 · Electricity and Magnetism

STUDY NOTES

Key terms

Molecular magnetism: unpaired electrons whose fields don't cancel make each atom or molecule a tiny magnet.

Paramagnetic: weakly attracted; weakly magnetized along the field; loses it when the field goes.

Ferromagnetic: strongly attracted; can be strongly magnetized; atomic magnets lined up in **domains**.

Diamagnetic: very weakly repelled (copper, gold, water, glass).

Curie temperature: above it, a ferromagnetic material becomes paramagnetic.

Primary cell: reaction can't be reversed. **Secondary cell** (storage cell, accumulator): recharged by a current passed the opposite way.

Shunt: low resistance in parallel. **Multiplier**: high resistance in series.

Semiconductor: conducts between a conductor and an insulator (silicon, germanium).

Doping: adding a few atoms per million of another element.

Diode: p–n junction; current in one direction only.
Depletion layer: thin layer at the junction with no free charges.

Transistor: npn or pnp; a small base current controls a much larger collector current.

Formulas

$V = I_g G$	G coil's resistance; I_g full-scale current **Use:** p.d. across the coil at full scale
$S = \frac{I_g G}{I - I_g}$	I largest current to read **Use:** shunt, for an ammeter
$R = \frac{V}{I_g} - G$	V largest voltage to read; meter's resistance $G + R$ **Use:** multiplier, for a voltmeter
$t = \frac{\text{capacity (Ah)}}{I}$	$I = P/V$; energy (Wh) = $P \times$ hours **Use:** how long a battery lasts

Magnetic materials

Paramagnetic	Ferromagnetic
weakly attracted	strongly attracted
atomic magnets random; a field lines up a tiny share (about 2 in 1,000)	lined up in domains; a field turns whole domains
no domains	domains (often under 0.1 mm)
all magnetism lost when field goes	hard ones keep it
Al, Pt, Na, Mn, oxygen	Fe, Co, Ni, Gd, steel, alnico

- paramagnetic: heat scatters them; colder → more strongly magnetized
- **soft** (soft iron): turns easily, keeps almost none; cores of electromagnets, transformers, galvanometer
- **hard** (steel, alnico): hard to turn, then stays; **permanent magnets**
- Curie:
  - iron 770 °C
  - nickel 354 °C
  - cobalt 1,127 °C
  - gadolinium about 19 °C
- drawing in a strong field: paramagnetic arrows only tilted; write "only a tiny share line up"

Secondary cells

Cell	V per cell	Used in
lead-acid	about 2	cars, Safa Tempos, inverters
NiCd	1.2	older tools, emergency lights
NiMH	1.2	AA, AAA, hybrid cars
lithium-ion	about 3.6–3.7	phones, laptops, electric cars

Lead-acid cell

- **positive plate**: lead dioxide, PbO_2, brown
- **negative plate**: spongy lead, Pb, gray
- **electrolyte**: dilute H_2SO_4, about 1.28 g/cm^3 when full
- plastic case, porous separators, vent cap
- many plates in parallel = large area; about 2 V (2.1 V full) whatever the size; 12 V = 6 cells in series
- **discharging**
  - negative: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$
  - positive: $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$
  - overall: $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$
  - both plates → lead sulphate; density falls to about 1.12 g/cm^3
- **charging**: charger + to +, − to −; every reaction reversed; density rises
- **gassing** near the end: water split, hydrogen at −, oxygen at +; explosive: airy place, no flame
- hydrometer: below about 1.15 g/cm^3 needs charging; sealed: voltmeter, 12.7 V full, 12.0 V about a quarter
- **uses**:
  - vehicles
  - inverters
  - solar storage
  - phones
  - telephone towers

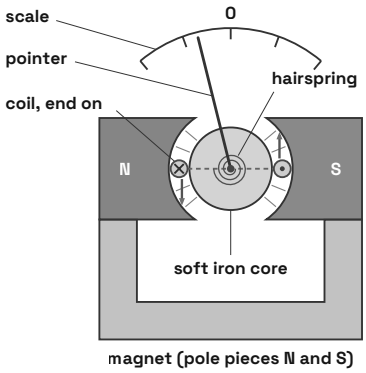
Primary	Secondary
can't recharge	hundreds or thousands of times
small current; fairly high internal resistance	large current (car: over 100 A); very low
costs less to buy, more over time	more to buy, less over its life
much waste; no charger needed	far less waste; needs a charger

Ammeter and voltmeter

Ammeter	Voltmeter
current (A)	potential difference (V)
in series	**in parallel**
very low resistance	very high (digital about 10 million Ω)
swapped: large current, can burn out	swapped: lamp dark, reads nearly the whole voltage

- positive terminal towards the cell's +; start on the highest range; read from directly in front

Galvanometer



- **parts**:
  - coil of fine copper on a light frame
  - horseshoe magnet with curved pole pieces
  - soft-iron core
  - two hairsprings (hold at zero, resist, lead current)
  - pointer and scale
- **working**: sides carry current opposite ways, motor effect, coil turns, twists springs until balanced
- deflection $\propto$ current; radial field (poles + core) $\rightarrow$ evenly spaced scale; reversed current $\rightarrow$ other way
- **ammeter**: low shunt, parallel; lets current **past**; whole meter below S
- **voltmeter**: high multiplier, series; **holds back** current
- example, 50 Ω, 10 mA: 0.5 V at full scale; 0–1 A: $S = 0.505$ Ω; 0–10 V: $R = 950$ Ω

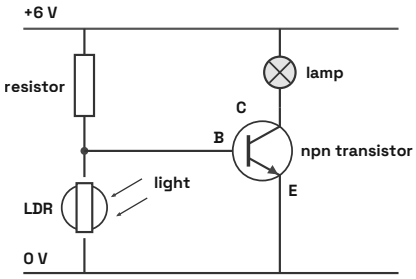
Semiconductors

- pure silicon conducts poorly; better with
  - **heat** (a metal gets worse)
  - **light** (LDR, solar cell)
  - **doping**
- **n-type**: 5 outer electrons (P, As); spare electrons move
- **p-type**: 3 outer electrons (B, Ga); **holes** move like + charges

Diode

- symbol's arrow: the way conventional current goes; band = cathode (n); other end anode (p)
- **forward**: p to +; holes and electrons pushed to the junction; flows above about 0.7 V (Si), 0.3 V (Ge)
- **reverse**: p to −; pulled away; depletion layer wider; practically no current
- with a lamp: $I = \dfrac{V - 0.7}{R}$; reversed: whole V across the diode
- **uses**:
  - rectifier (half-wave; four in a bridge)
  - LED
  - solar cell
  - protection

Transistor



- terminals: emitter, base (thin middle), collector; arrow on emitter: out for npn, in for pnp
- base needs about 0.7 V; collector current typically about 100 × base
- **switch**: computer chips, street lights, alarms, inverters
- **amplifier**: radios, hearing aids, audio
- night light: dark $\rightarrow$ LDR resistance rises $\rightarrow$ base above 0.7 V $\rightarrow$ lamp on; base voltage = supply $\times \dfrac{R_{LDR}}{R + R_{LDR}}$

COMMON MISTAKES

✗ bigger cell, higher voltage
✓ about 2 V; size sets the **charge**.

✗ density rises in use
✓ **falls**; acid used up, water made.

✗ shunt in series, multiplier in parallel
✓ **shunt parallel, multiplier series**.

✗ $S = I_g G / I$
✓ divide by $I - I_g$.

✗ mA left as mA
✓ change to **A**.

✗ paramagnets drawn neatly lined up
✓ only a tiny share line up.

✗ diode has no voltage drop
✓ take off about **0.7 V**.