Fall Semester, 2011
Energy Engineering
에너지공학

Solar Energy and Solar Cell

ch. 6

Introduction

Average solar power incident on the earth ~1000 W/m^2 (~100 mW/cm^2), ~100,000 TW
(cf. world power consumption ~15 TW)

Photovoltaics: ~2.5 GW (2004), ~1000 GW (2030)

Issues: price & efficiency

1. The solar spectrum

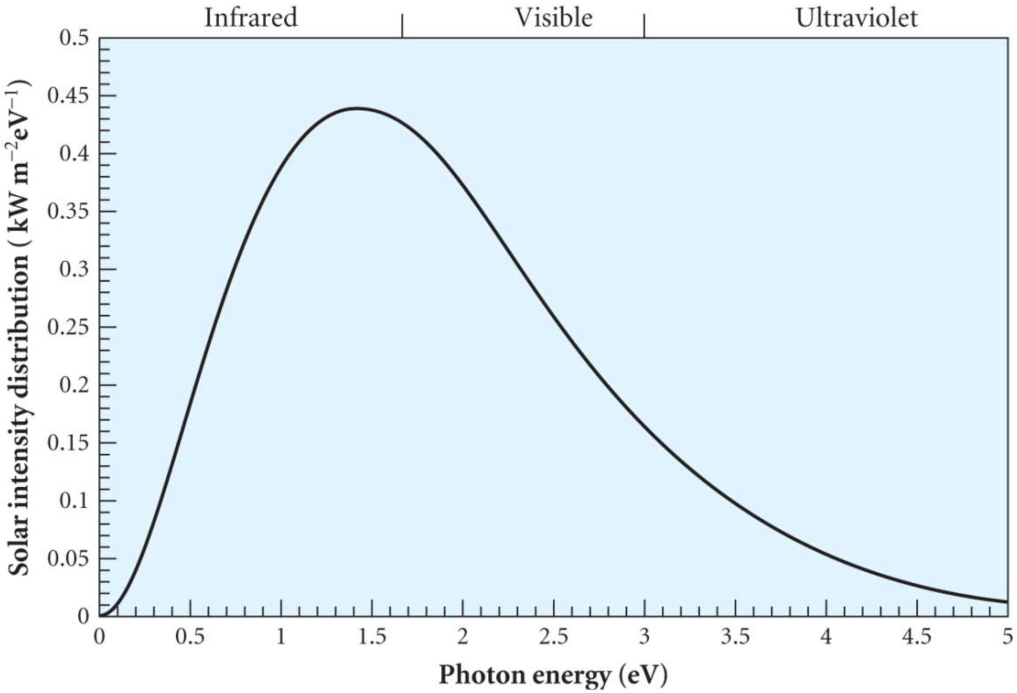
Blackbody at 5800 K: similar spectral shape from the Sun on the Earth's atmosphere

Intensity: 1.36 kW/m2 for sunlight incident on the atmosphere (AM0) to 1.0 kW/m2 after passing 1.5 times thickness of the Earth's atmosphere (AM1.5, sunlight incident at 48° to the vertical)

Visible: ~3 ~1.7 eV (400~700 nm)
IR: <1.7 eV

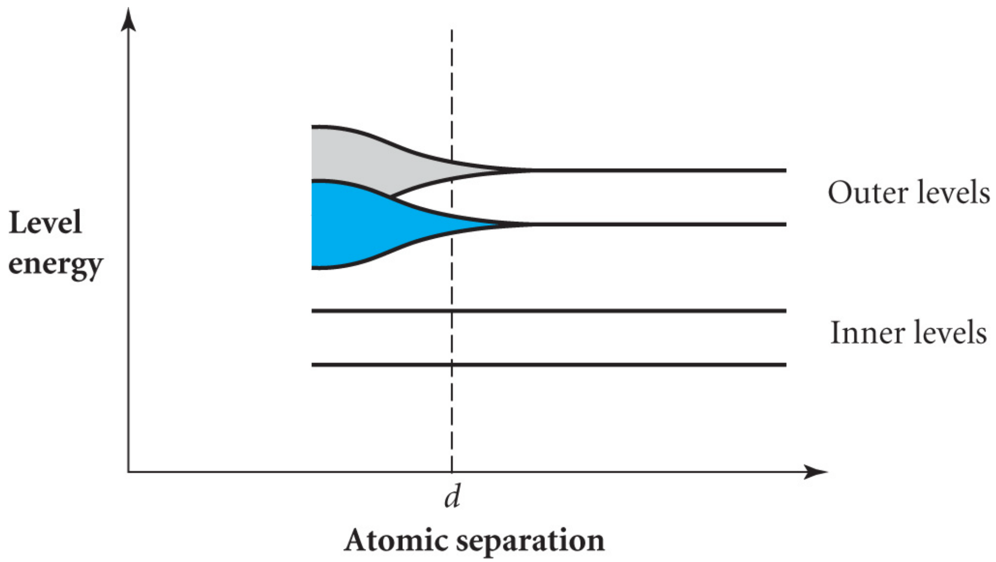
e.g. 6.1

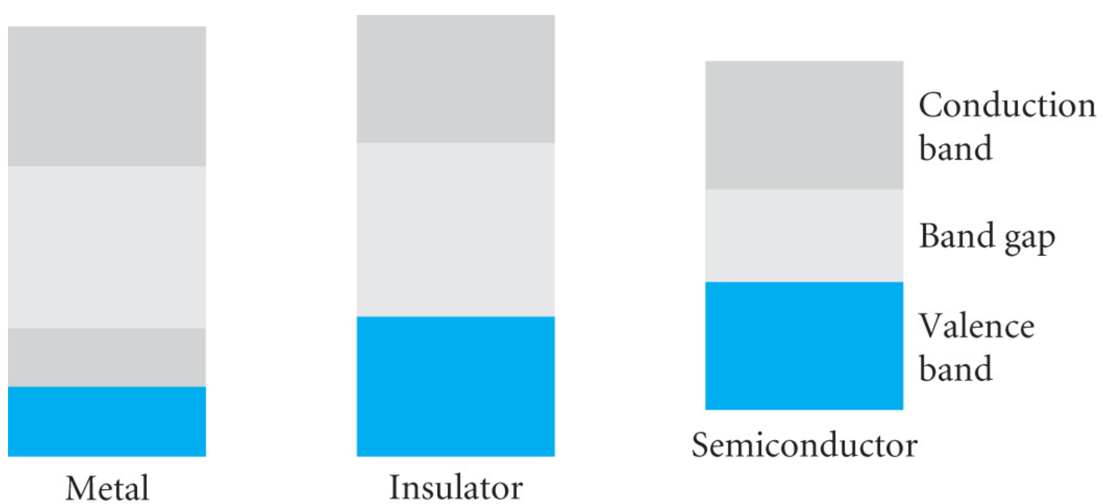
e.g. 6.2



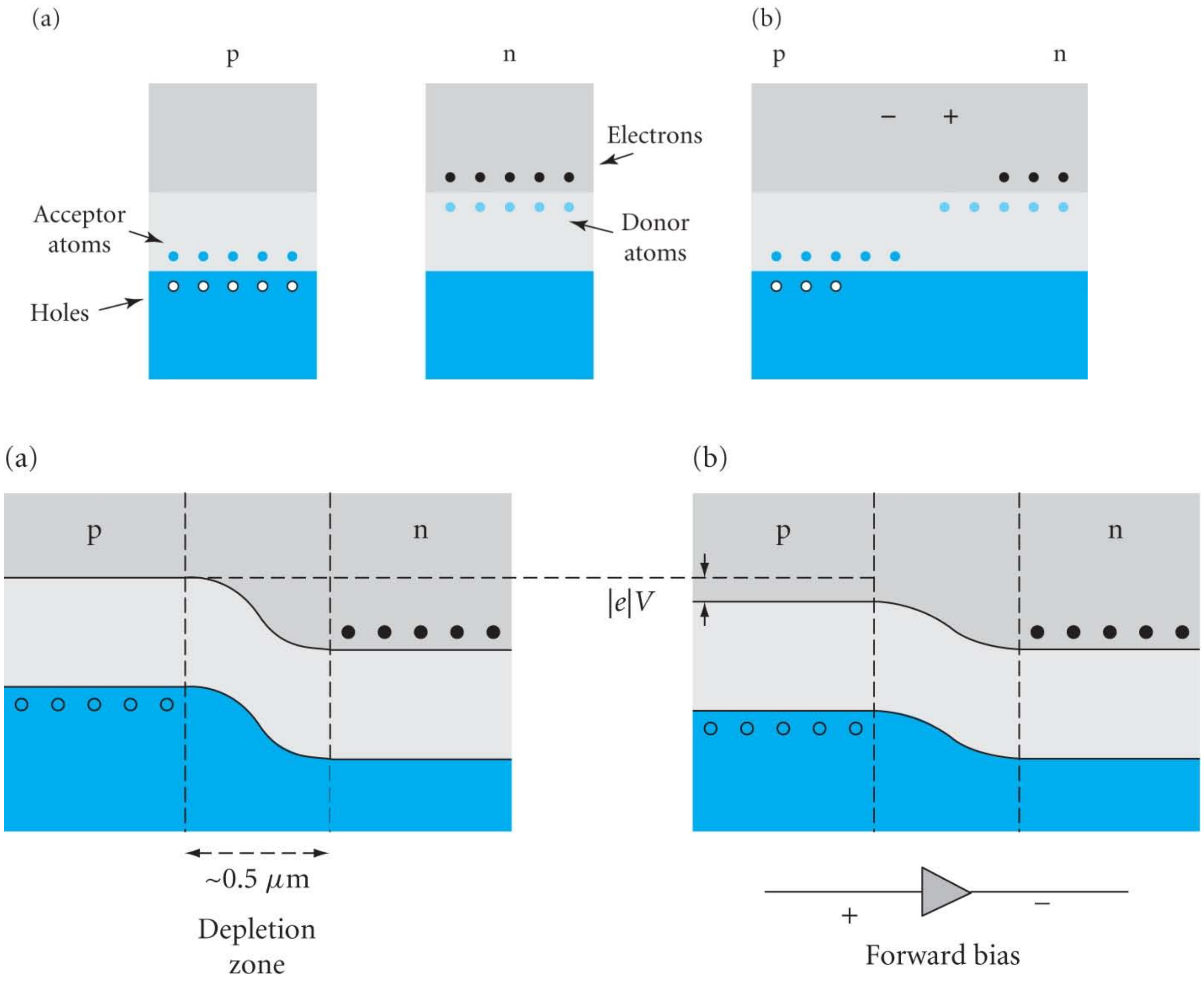
2. Semiconductors

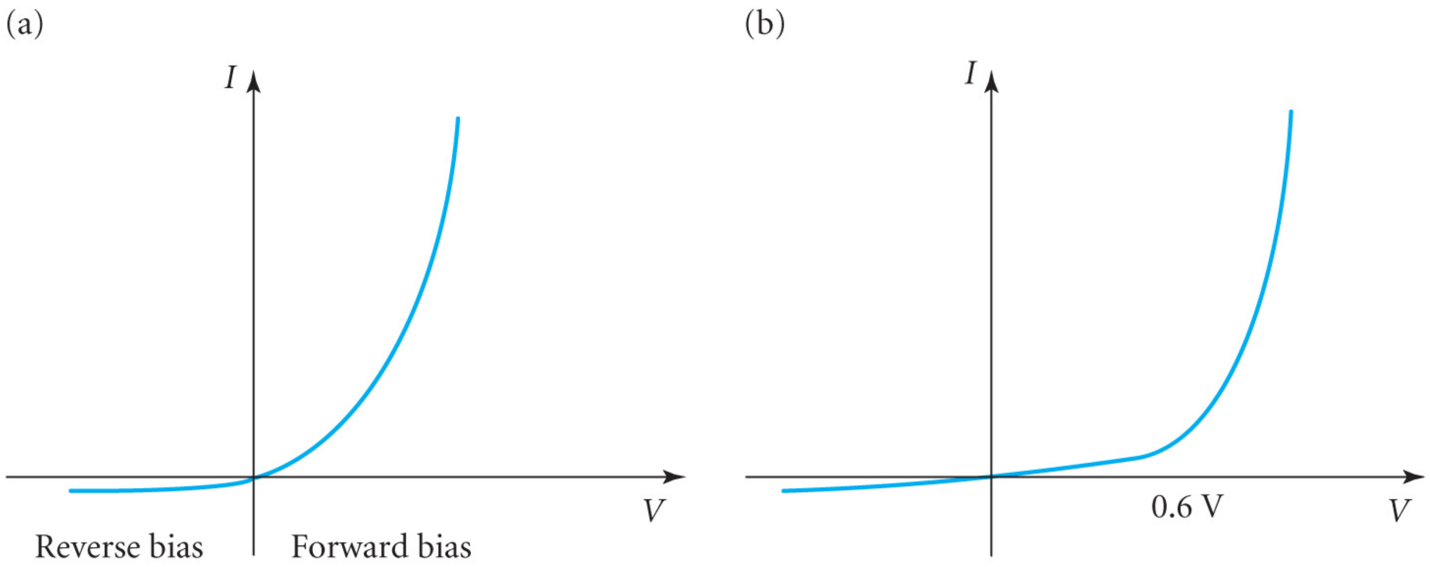
Materials for photovoltaics: semiconductor





3. p-n junction





I-V curve for ideal p-n junction   actual I-V curve for Si diode

Total forward current

$$I = I_s\{\exp(V/V_T) - 1\}$$

where I_s is saturation current, $V_T = kT/e \sim 0.026$ eV

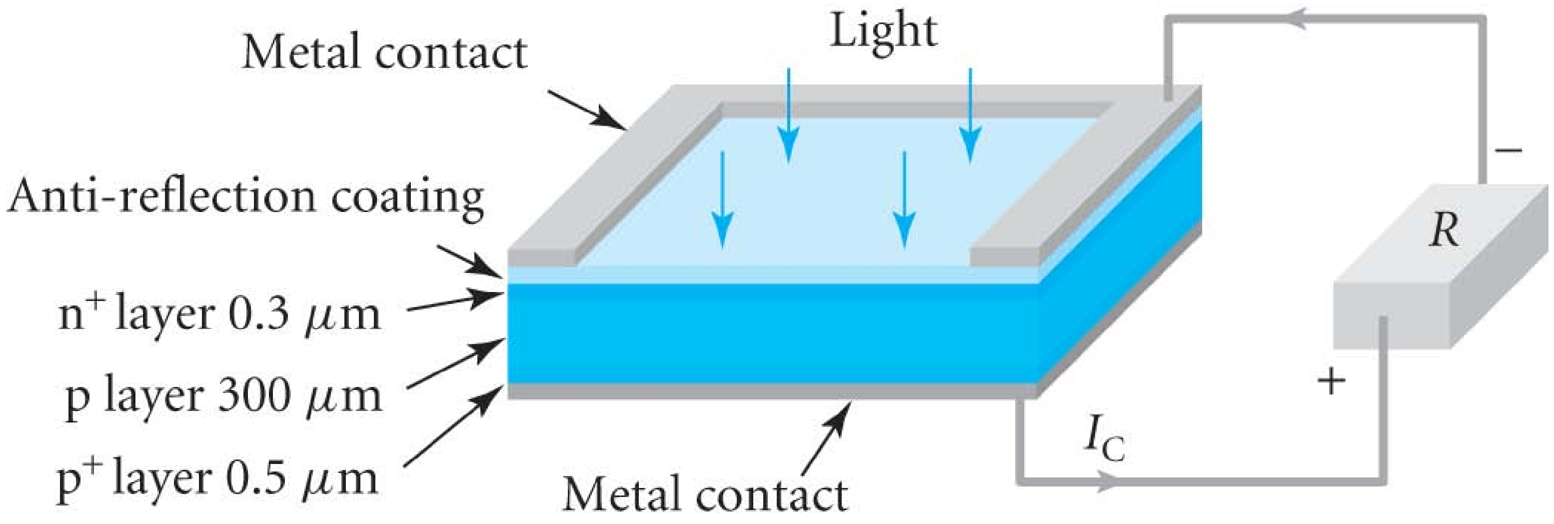
(Derivation 6.1)

4. Solar photocells

Photoelectric effect: light on a Si p-n junction → electron-hole pairs

Minimum energy = band gap

e.g. Si: 1.1 eV → 1240/1.1 = 1100 nm



The photocell current

$$I_C = I_L - I_s\{\exp(V/V_T) - 1\} = I_L - I_s\{\exp(I_C R/V_T) - 1\}$$

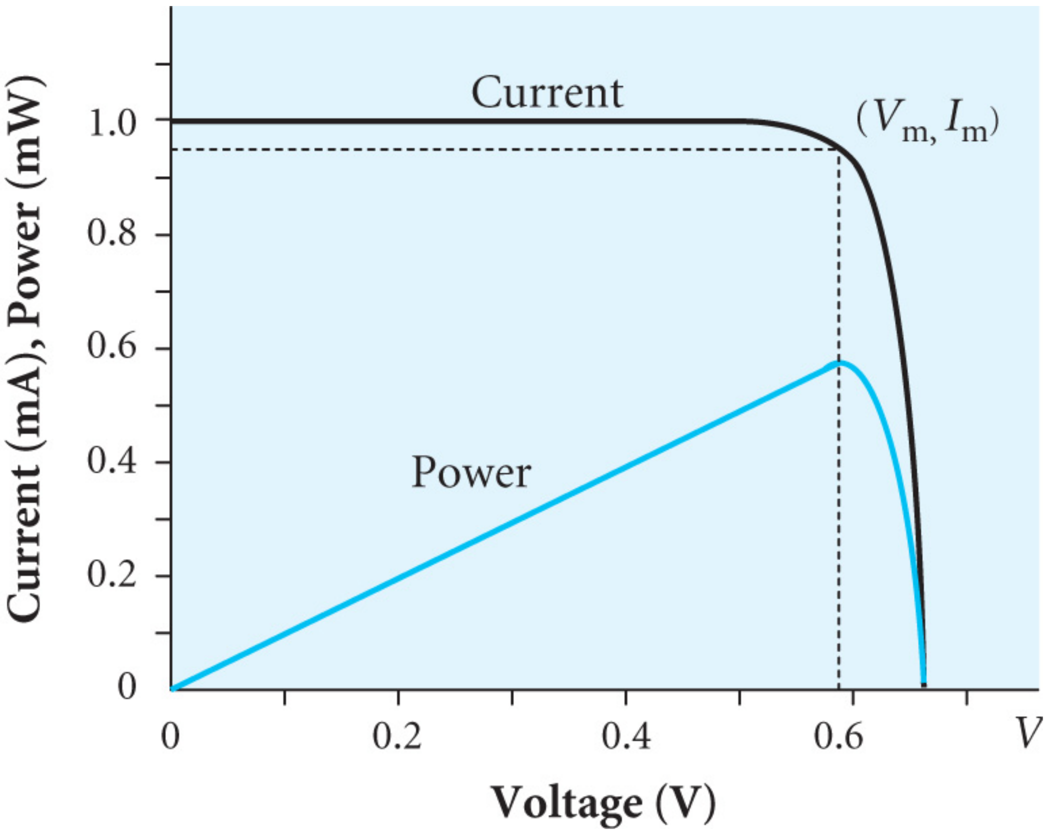
where light-induced current I_L (as the electrons flow across the junction from the p- to the n-side)

Power, $P_C = I_C V = I_C^2 R$

Open circuit voltage (V_{OC})
Short ccircuit current (I_{SC})
Maximum power ($P_m = V_m I_m$)
Fill factor, $FF = P_m/(I_{SC} V_{OC})$
Good solar cell: FF > 0.7

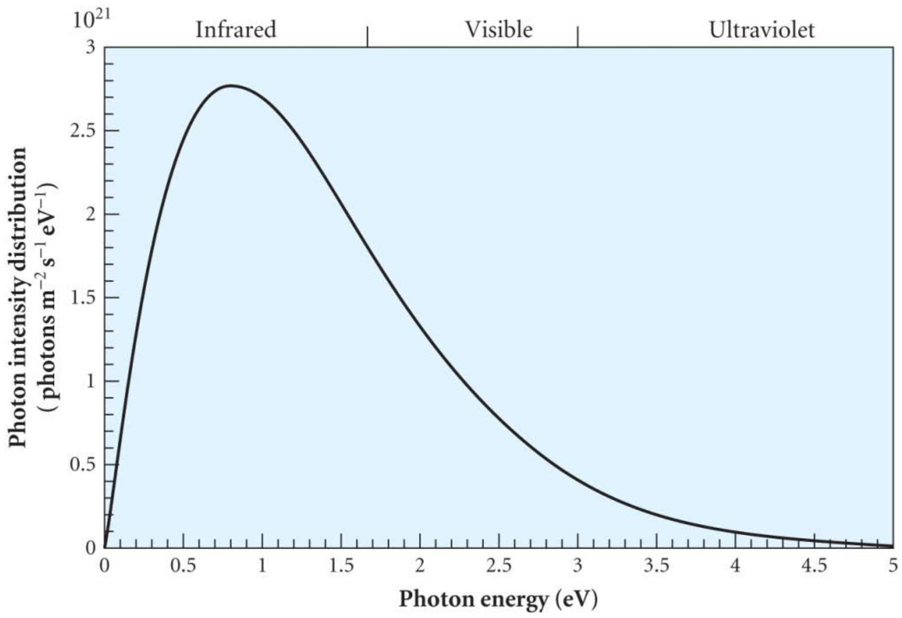
Table 6.1

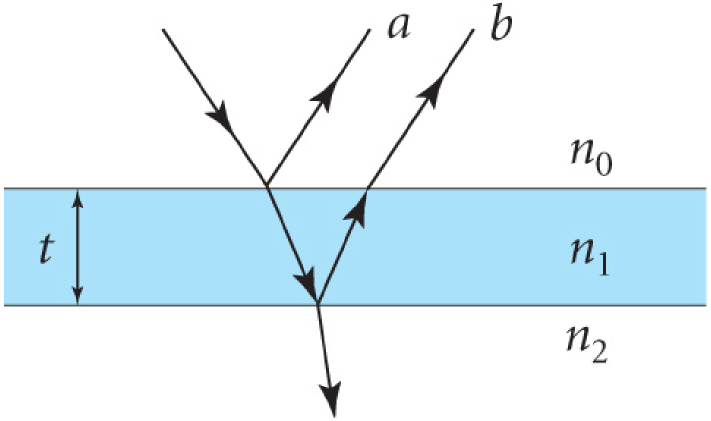
e.g. 6.3



5. Efficiency of solar cells

Conversion efficiency: the ratio of the maximum power output to the incident power (for AM1.5 ~100 mW/cm^2)



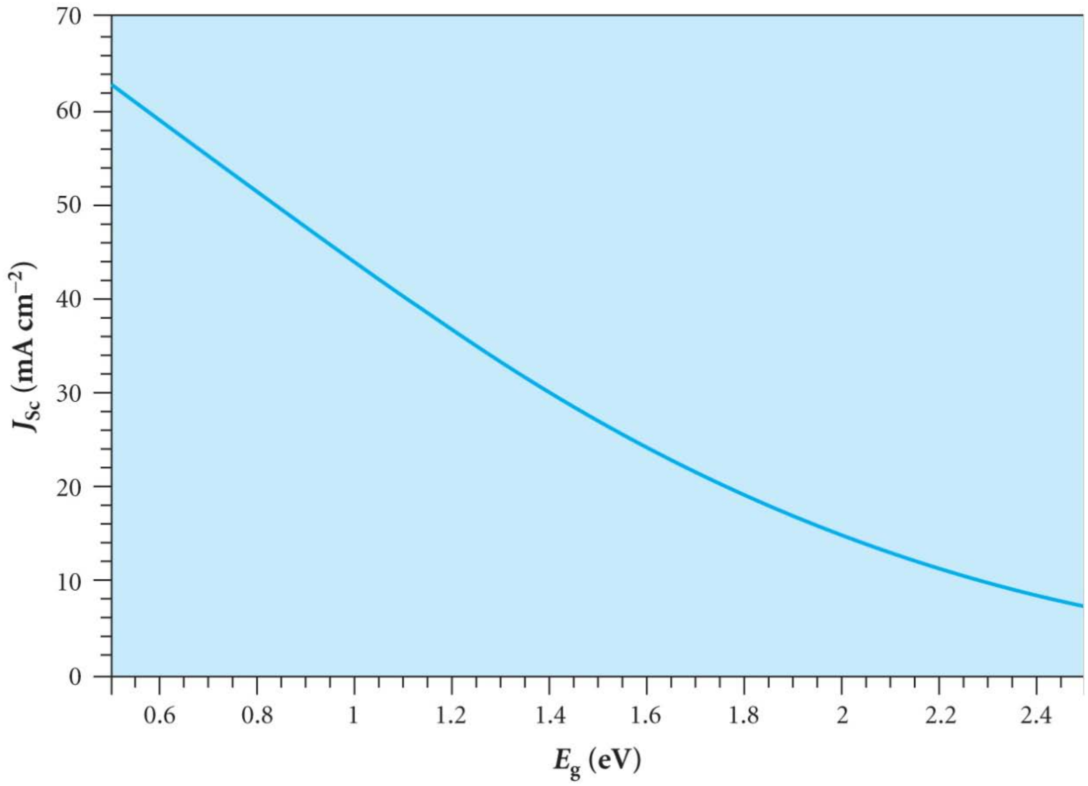


Overall efficiency ~26%

Optimum band gap ~1.4 eV

Derivation 6.2 Efficiency vs. band gap

J_{SC} vs. band gap

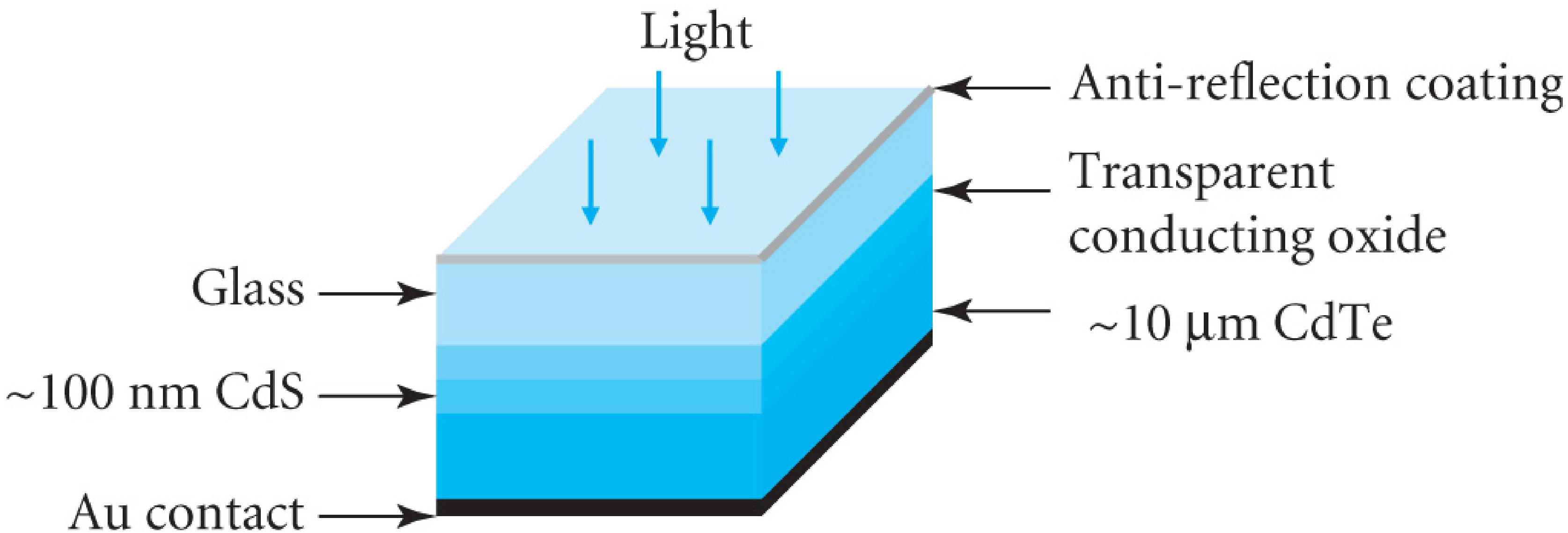


6. Commercial solar cells

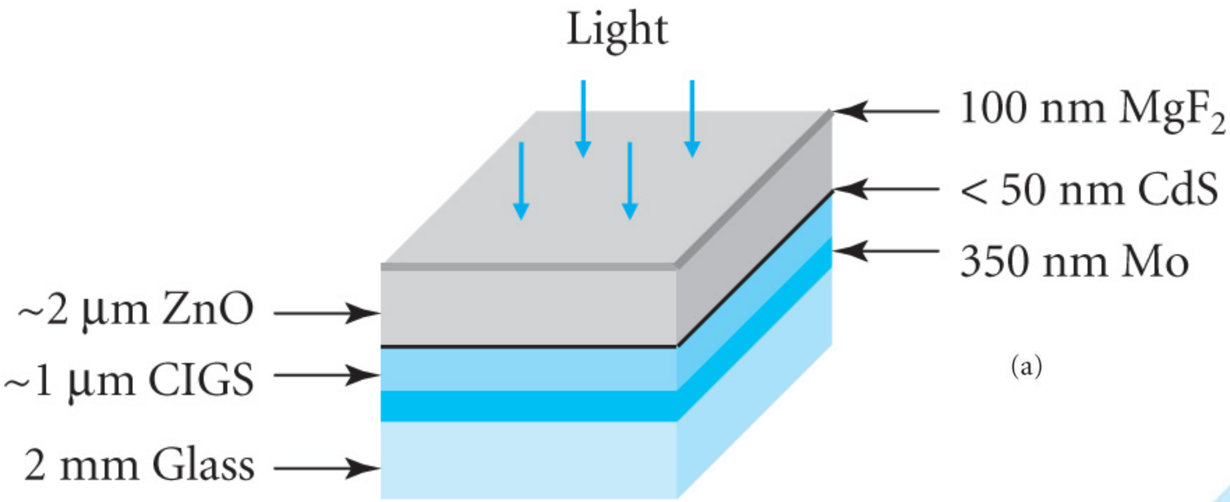
6.1. Crystalline Si cells

6.2. Thin-film cells

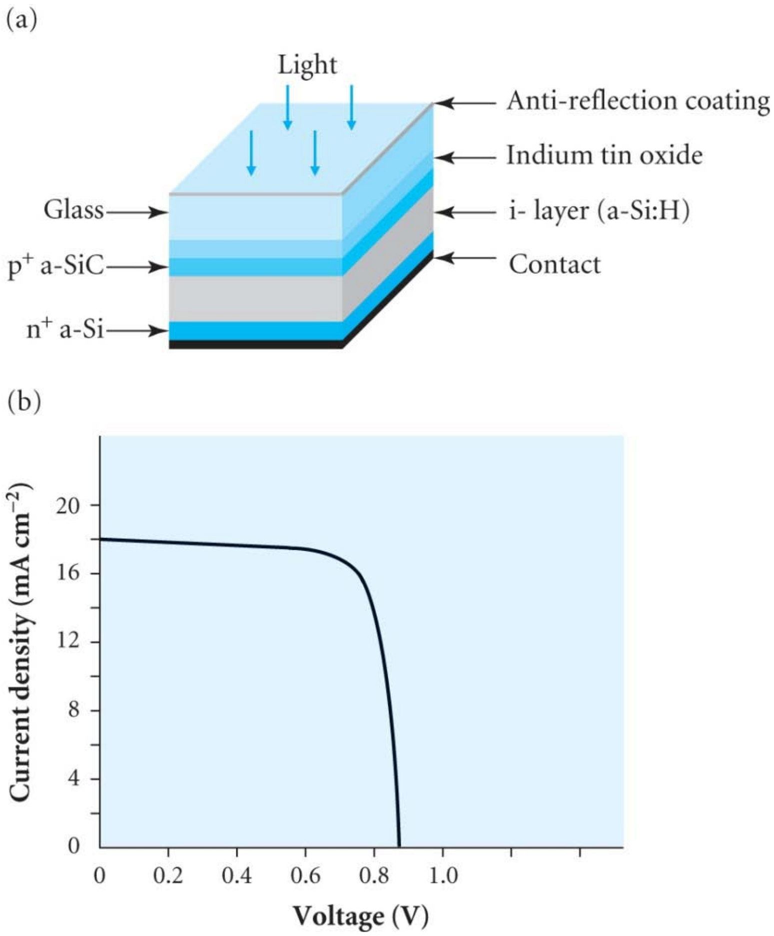
-CdTe solar cells



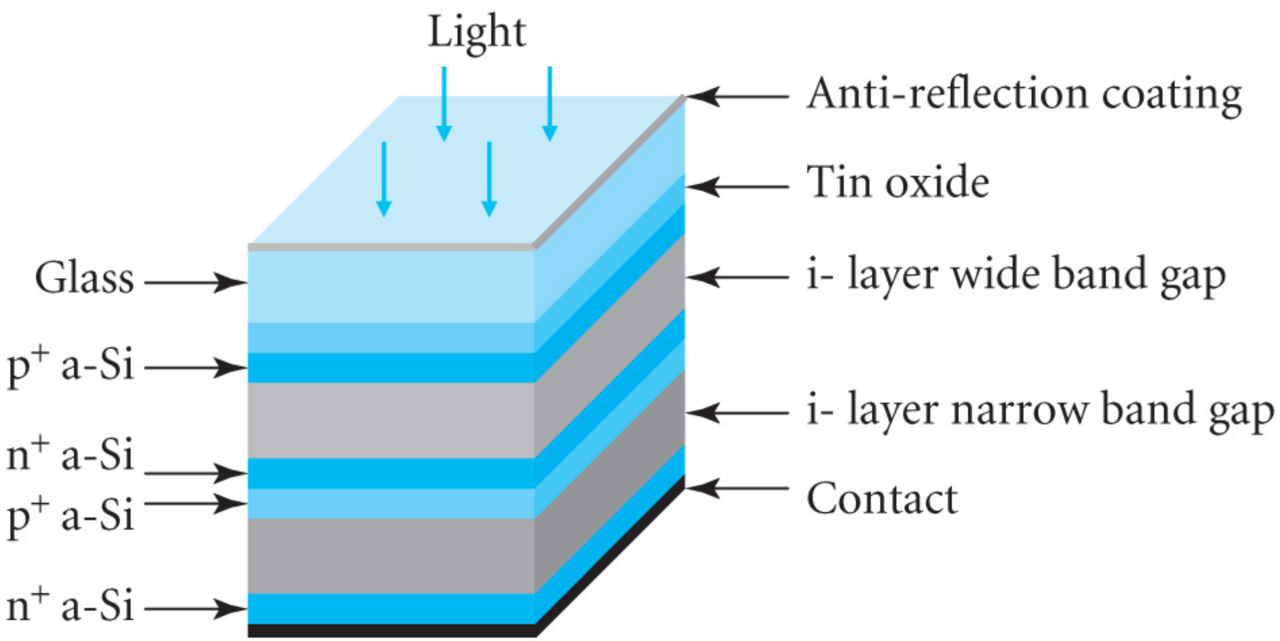
-CIGS solar cells



-Amorphous Si solar cells

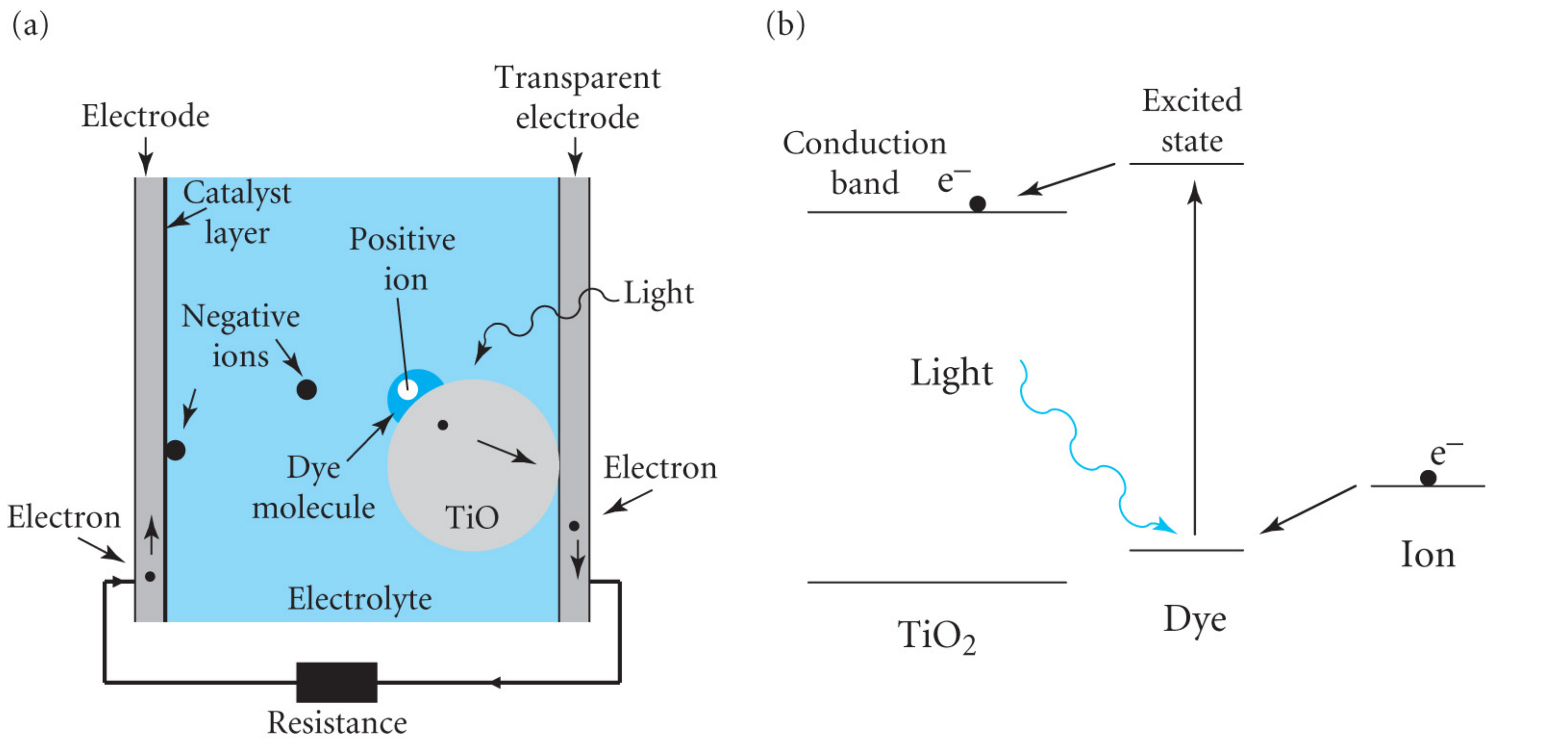


-Multilayer thin film cells



7. Developing technologies

7.1. Electrochemical cells

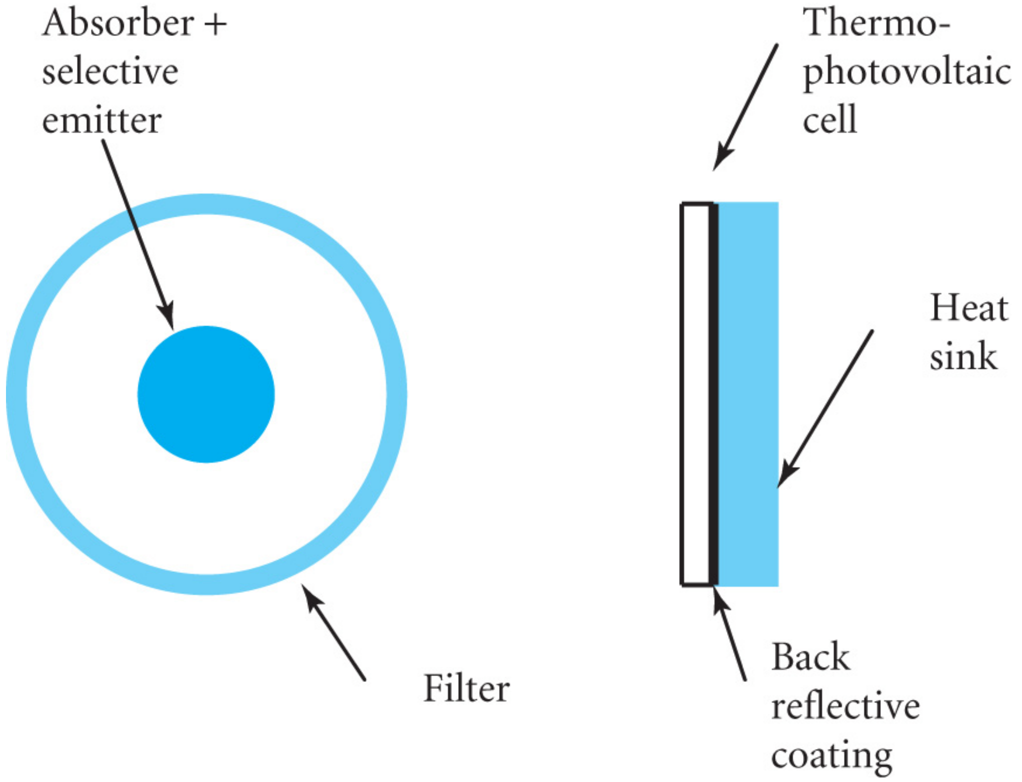


7.2. Concentrators

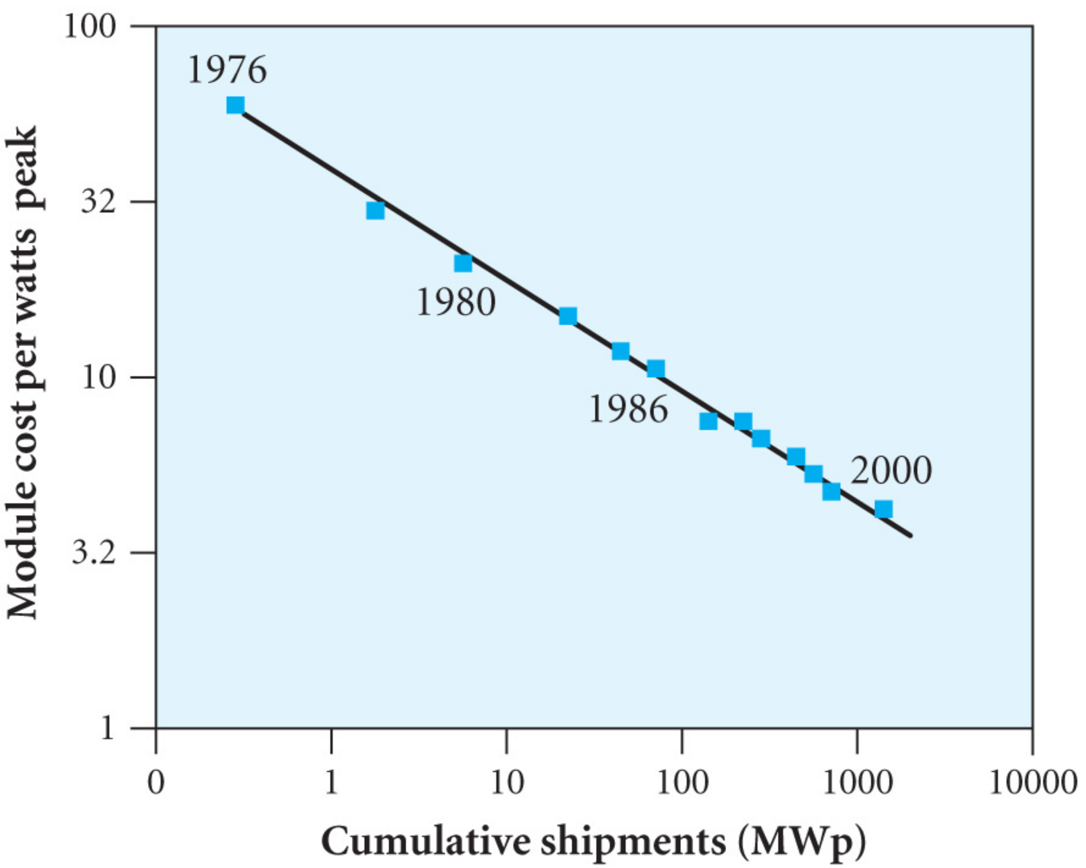
7.3. Organic semiconductor solar cells

7.4. Thermo-photovoltaic cells (TPC)

e.g. 6.6



8. Solar panels



e.g. 6.7

9. Economics of PVs

Panel price has dropped significantly

Solar power unit: Panel cost 40~50%, installation 50~60%

Cost of connection to a grid can be ~$5000 per km: battery storage systems

에너지 가격 비교

석탄	4~9 센트/kWh	1200 유로/KW
천연가스	3-5	550
풍력	3-10	750-1000
수력	3-14	900
바이오매스	7-20	1100
태양전지	25-30	5000-9000

2009년 각국 전기세(kWh당): 미국 115.48원, 프랑스 142.19원, 영국 184.39원, 일본 202.3원, 우리나라 83.59원 → 일본, 독일은 태양전지 유리

10. Environmental impact of PVs

No pollutants and no greenhouse gases in operation. No noise

Large area required: annual 10~40 MW from 1 km2

Pollutants & energy during manufacturing→ longer lifetime (30 yrs)

11. Outllok for PVs

Fast increase in the production of PV panels: 64% in 2003 → 2004. 927 MWp (2003) to 3.26 GWp (2010)

Solar industry depends on silicon industry ~US$2/Wp (2010)

Thin film technologies, both Si and non-Si, are needed for US$1/Wp

low-carbon electricity → great potential (Shell: 15~20% energy from PV in 2060

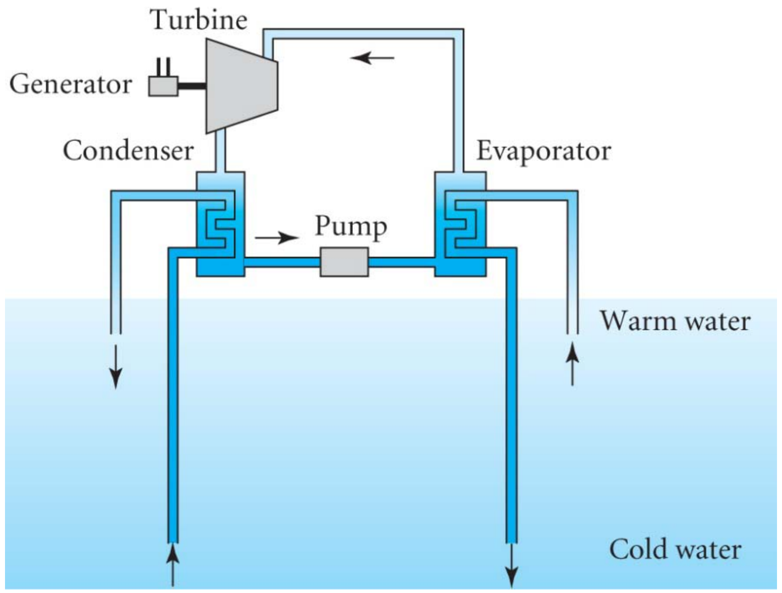
12. Solar thermal power plants

Solar radiation → heating
-e.g., sun's ray to heat oil or molten salt (>500°C)
California: 80 MW from heated oil (~390°C) by ~500,000 m^2 parabolic collectors (efficiency ~18%)

12.1. Ocean thermal energy conversion (OTEC)

~1000 MW on km2 of sea →
ocean top hundred meters: 20~25°C higher than deep (<1000 m)

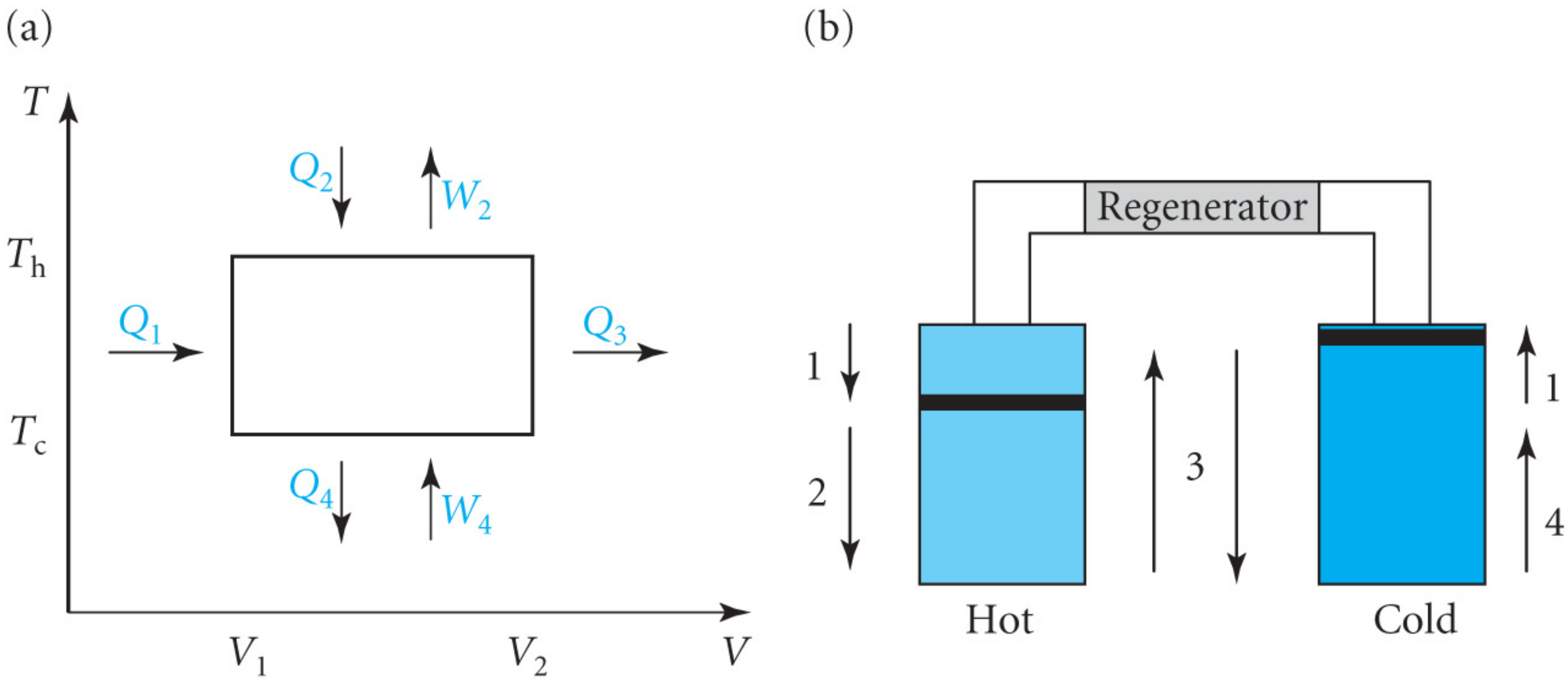
Carnot efficiency = $(T_h - T_c)/T_h = \Delta T/T_h$



12.2. Solar driven stirling engines

Stirling engine + solar collecting dishes
e.g., 2005, California: 20,000 dishes (11 x 11 km) → 500 MW
- each dish: 82 mirrors (90 m^2), conversion efficiency ~30%
- max temp of sealed hydrogen gas in the Stirling engine ~720°C
- $2/W (competitive with current solar panels)

Stirling engine: heat & cool the sealed gas

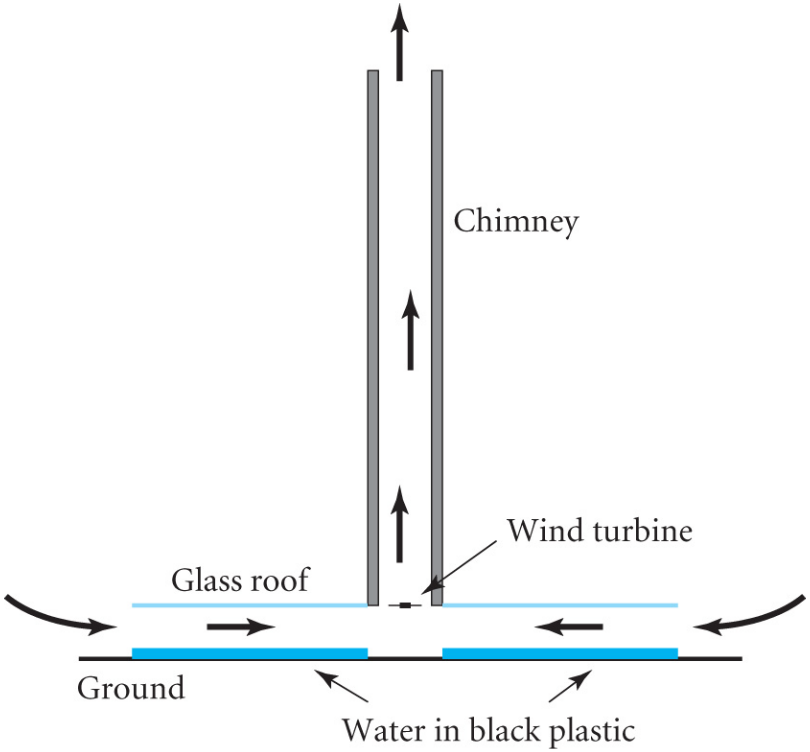


12.3. Solar chimneys

1980s Spain: chimney 195 m tall, 10 m in dia.
Solar collector 240 m in dia.
→ 50 kW

Australia (plan): 200 MW
1000 m tall, 150 m dia
collector: 5000 m
물을 데워 공기로 열전달: 24 시간 가동
20만 가구에 전기 공급
conversion efficiency ~2%

Cost: $0.15/kWh



$\Delta p_o = \rho_o gh$, $\Delta p_i = \rho_i gh$
$\rho_i < \rho_o$ → bottom: $p_i < p_o$, top: $p_i > p_o$
→ drive air from bottom to top