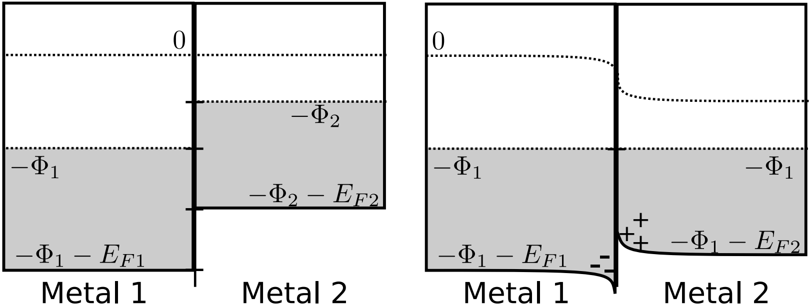
MTLE-6120: Advanced Electronic Properties of Materials

Metal-metal junctions,
Seebeck effect, thermocouples, Peltier effect

Reading:

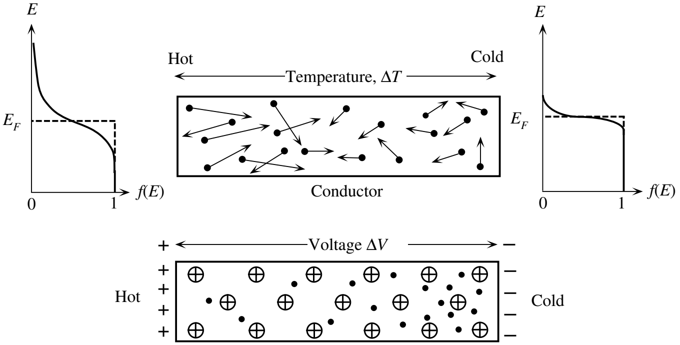
- Kasap 4.8

Contact potential



- Interface between two metals with different work-functions
- Fermi levels at different absolute energies (relative to vacuum)
- Is this in equilibrium?
- Electrons flow across interface to equalize Fermi-levels (chemical potential)
- Bands bend up/down near interface due to potential (on Å scale in metals)
- Contact potential at interface $e\Delta V = \Phi_1 - \Phi_2$
- Cannot do work: $\sum_{\text{loop}} \Delta V = 0$ (why?)

Seebeck effect



- Set up a temperature gradient across a metal
- Thermal conductivity: higher E electrons diffuse from hot to cold side
- Net electron transfer to cold side $\Rightarrow$ potential difference opposite ΔT
- Seebeck coefficient: $S(T) = \mathrm{d}V/\mathrm{d}T$ (expect $S < 0$ based on above)
- Potential difference $\Delta V = \int S(T)\mathrm{d}T$

Figure 4.30 from Kasap

Seebeck coefficients

Metal	$S(T=0\text{C})$ [μV/K]	$S(T=27\text{C})$ [μV/K]	E_F [eV]	x
Al	-1.6	-1.8	11.6	2.78
Mg	-1.3		7.1	1.38
Au	+1.79	+1.94	5.5	-1.48
Cu	+1.70	+1.84	7.0	-1.79

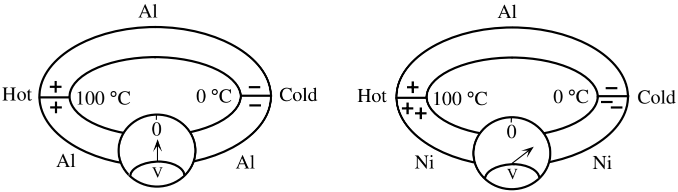
- Intuitive argument $\Rightarrow S < 0$, but metals exhibit both signs
- Mott-Jones equation defines x above:

$$S \approx -\frac{\pi^2 k_B^2 T}{3eE_F} x \qquad \text{with} \qquad x \equiv E_F \frac{\mathrm{d}}{\mathrm{d}E_F} \ln \sigma(E_F)$$

  where $\sigma(E_F)$ is the electronic conductivity at a given E_F

- Positive $S \Rightarrow \sigma \uparrow$ as $E_F \downarrow$ (or higher σ below Fermi level than above)
- What does the sign of the Seebeck coefficient mean?

Thermocouple



- In closed loop in single metal: $V = 0$
- If two junctions at different temperature: $\Delta V = \int_{T_\mathrm{cold}}^{T_\mathrm{hot}} \mathrm{d}T \delta S(T)$ where ΔS is difference between Seebeck coefficients in two materials
- Most common method of measuring temperature in lab
- Materials with high enough Seebeck coefficients: electrical energy harvesting from $k_B T$!

Figure 4.32 from Kasap

Thomson and Peltier effects

- Pass current density $\vec{j}$ through material with temperature gradient ∇T generates heat per unit volume

  $$\dot{q} = -\mathcal{K}\vec{j} \cdot \nabla T$$

  with Thomson coefficient $\mathcal{K} = T\mathrm{d}S/\mathrm{d}T$

- Flow current I across a metal-metal junction produces heat at rate:

  $$\dot{Q} = (\Pi_1 - \Pi_2)I$$

  where $\Pi_{1/2} = TS_{1/2}$ is the Peltier coefficient
- Basically the opposite of the Seebeck effect:
  charge flow generates thermal gradient
- In current loop with two metals: heat extracted in one junction,
  dissipated in other $\Rightarrow$ refrigeration!
- Solid-state cooling using Peltier effect replacing LN2 in many cryo systems
- All solid-state superconducting devices combining
  Peltier coolers with high T_c superconductors!