Metal as classical gas: Drude model

resistivity measurements

thermoelectrics

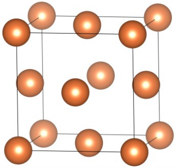
Paul Drude

by Alexander Tsirlin, Leipzig University

Lecture 17: December 7, 2023

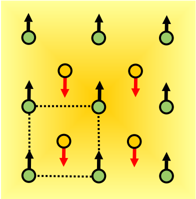
1. Structure of crystals

- direct lattice / reciprocal lattice
- symmetry
- crystal structure / structure factor



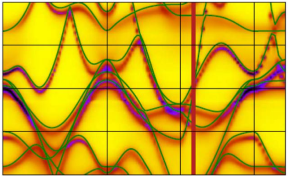
2. Atoms in crystals

- types of bonding
- elasticity and thermodynamics
- phonons (lattice vibrations)



3. Electrons in crystals

- free electron gas / Drude metal
- electronic band structure
- Fermi surface



Resistivity = specific resistance

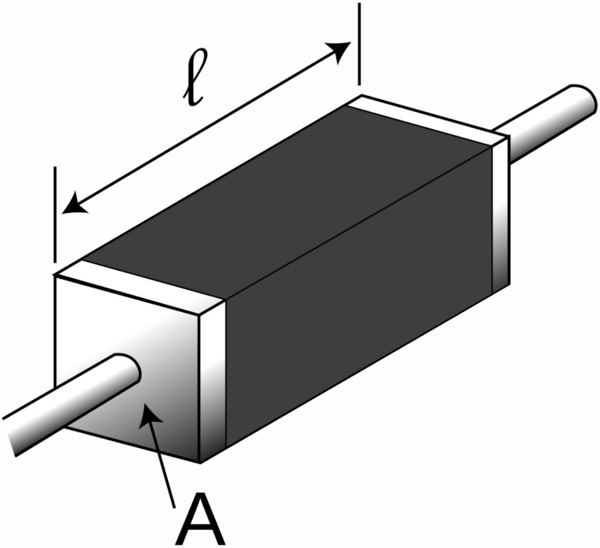
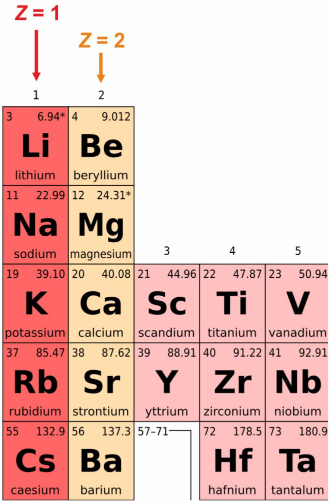


Image credit: Omegatron (CC-BY-SA)

Electron concentrations

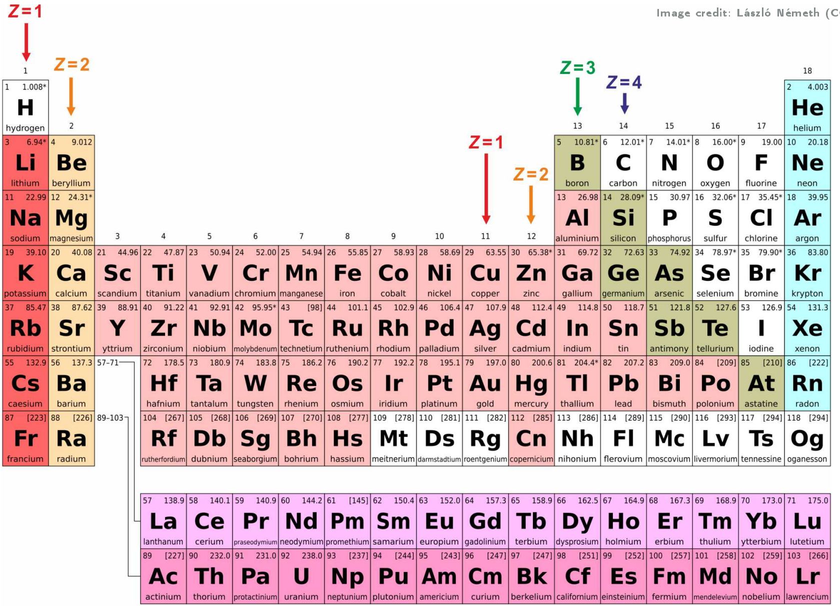
ELEMENT	Z	$n\ (10^{22}/\text{cm}^3)$
Li (78 K)	1	4.70
Na (5 K)	1	2.65
K (5 K)	1	1.40
Rb (5 K)	1	1.15
Cs (5 K)	1	0.91
Cu	1	8.47
Ag	1	5.86
Au	1	5.90
Be	2	24.7
Mg	2	8.61
Ca	2	4.61
Sr	2	3.55
Ba	2	3.15



Source: Ashcroft and Mermin, Solid State Physics

Valence of metals

Image credit: László Németh (CC-zero)



Source: Ashcroft and Mermin, Solid State Physics

Resistivity: ρ $(10^{-8}\,\Omega{\cdot}\mathrm{m})$

ELEMENT	77 K	273 K	373 K
Li	1.04	8.55	12.4
Na	0.8	4.2	Melted
K	1.38	6.1	Melted
Rb	2.2	11.0	Melted
Cs	4.5	18.8	Melted
Cu	0.2	1.56	2.24
Ag	0.3	1.51	2.13
Au	0.5	2.04	2.84
Be		2.8	5.3
Mg	0.62	3.9	5.6
Ca		3.43	5.0
Sr	7	23	
Ba	17	60	

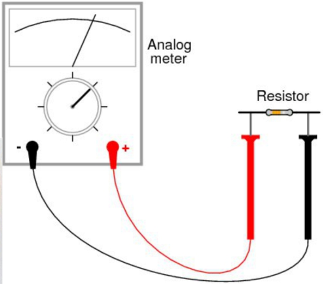
n_e ↑ (Li–Cs): $Z = 1$

n_e ↑ (Be–Ba): $Z = 2$

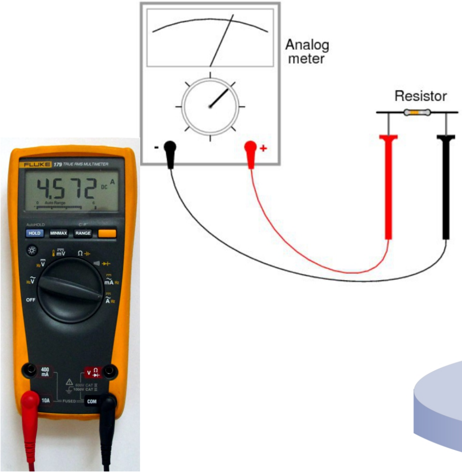
Experimental technique

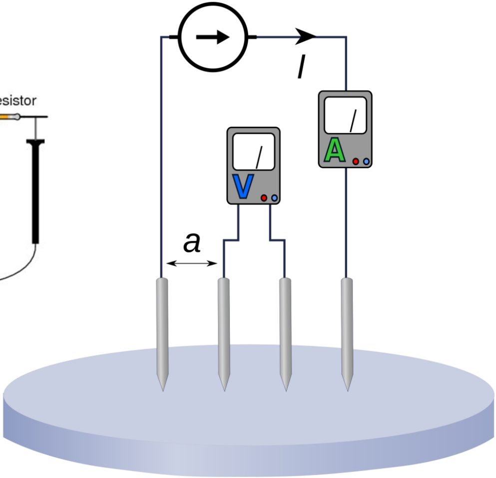
resistivity measurements

Two-probe vs. four-probe



Two-probe method





Two-probe method

contact resistance

Four-probe method

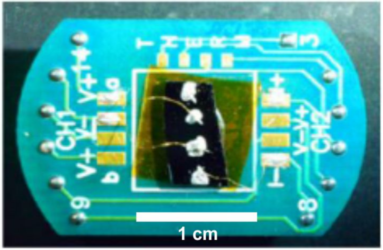
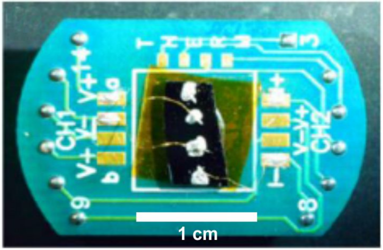
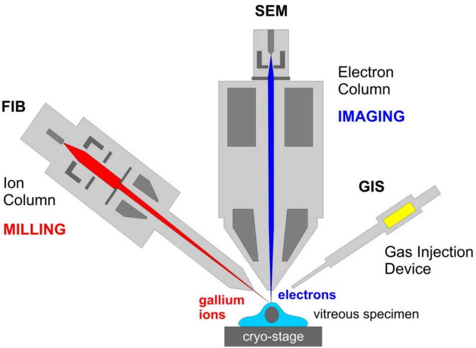


Image credits: Seyed Majid Mohseni (PhD thesis); Archives Biochem. Biophys. 581, 122 (2015); npj 2D Mater. Appl. 4, 7 (2020)





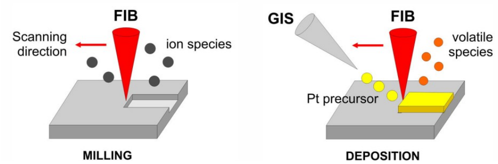
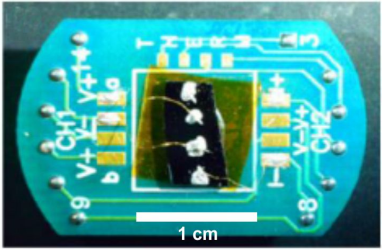
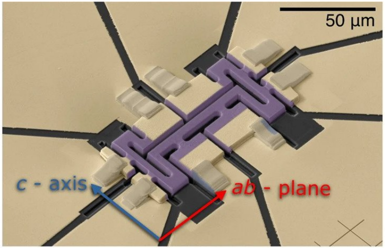
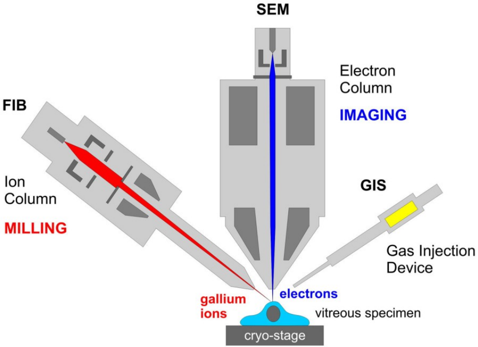
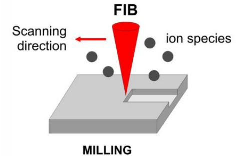


Image credits: Seyed Majid Mohseni (PhD thesis); Archives Biochem. Biophys. 581, 122 (2015); npj 2D Mater. Appl. 4, 7 (2020)









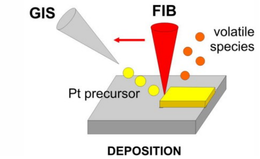


Image credits: Seyed Majid Mohseni (PhD thesis); Archives Biochem. Biophys. 581, 122 (2015); npj 2D Mater. Appl. 4, 7 (2020)

ELEMENT	273 K κ (watt/cm-K)	273 K $\kappa/\sigma T$ (watt-ohm/K^2)	373 K κ (watt/cm-K)	373 K $\kappa/\sigma T$ (watt-ohm/K^2)
Li	0.71	2.22×10^{-8}	0.73	2.43×10^{-8}
Na	1.38	2.12		
K	1.0	2.23		
Rb	0.6	2.42		
Cu	3.85	2.20	3.82	2.29
Ag	4.18	2.31	4.17	2.38
Au	3.1	2.32	3.1	2.36
Be	2.3	2.36	1.7	2.42
Mg	1.5	2.14	1.5	2.25
Nb	0.52	2.90	0.54	2.78
Fe	0.80	2.61	0.73	2.88
Zn	1.13	2.28	1.1	2.30

Source: Ashcroft and Mermin, Solid State Physics

Person

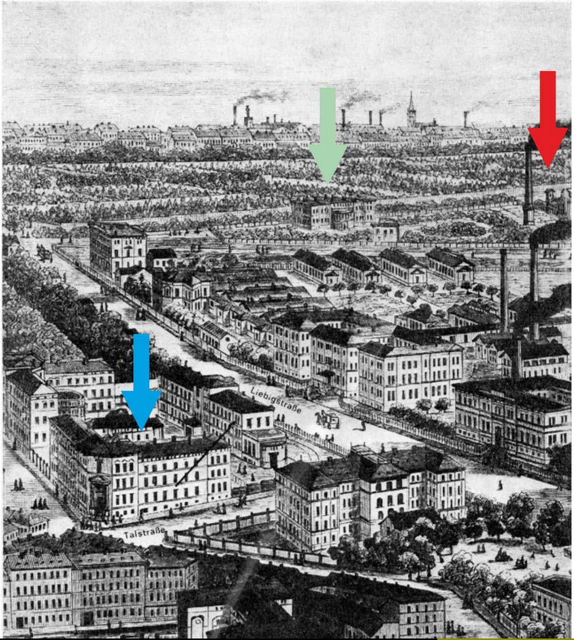
Paul Drude

Paul Drude

Paul Drude

1863–1906

- 1880's: studied mathematics and physics in Göttingen
- 1887: PhD on reflection and diffraction of light in crystals
- 1894–1900: associate professor in Leipzig
- 1890's: optical properties of metals
- 1900: formulated first theory of metals (Drude model)



new building (Linnéstraße) opens 1905

botanical garden

old building (Talstraße 35)

Image source: Ann. Phys. (Leipzig) 15, 449 (2006)

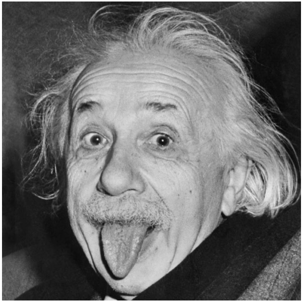
Paul Drude

1863–1906

- 1880's: studied mathematics and physics in Göttingen
- 1887: PhD on reflection and diffraction of light in crystals
- 1894–1900: professor in Leipzig
- 1890's: optical properties of metals
- 1900: formulated first theory of metals (renowned Drude model)
- 1901–1905: professor in Giessen
- since 1905: director of the Physics Institute in Berlin
- 1906: member of the Prussian Academy of Sciences

Einstein vs. Drude

Albert Einstein
1879–1955



Paul Drude
1863–1906

Albert Einstein about Paul Drude:

"What you say about German professors is unfortunately true. Drude discarded two objections, which I raised against his theory and which demonstrate a direct mistake in his conclusions, by pointing out that another (infallibe) colleague of his shares his opinion.

Authority gone to one's head is the greatest enemy of truth"

English translation per Ann. Phys. (Leipzig) 15, 449 (2006)

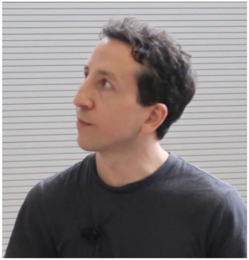
Physics Colloquium

Tuesday, 12 Dec 2023 at 16:30

Prof. Dr. Krzysztof Wohlfeld

University of Warsaw

Spinons or magnons? A quest for the correct quasiparticle description of quantum magnets

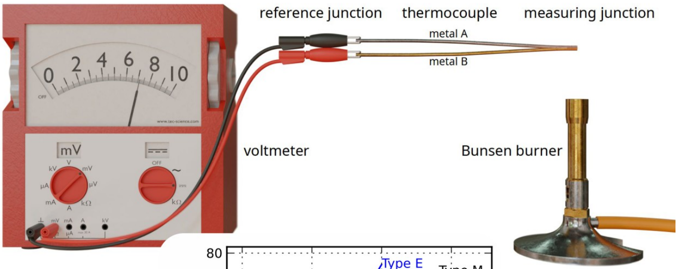


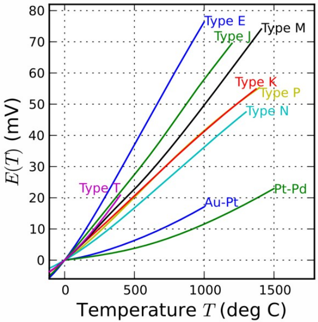
One of the main paradigms of quantum magnetism is that collective excitations in systems with long-range order, such as ferro/antiferro-magnets, are well described in terms of bosonic quasiparticles – magnons. This approach is extremely successful, since these magnons interact very weakly. On the other hand, once the long-range order collapses, for instance due to geometric frustration of spin couplings, magnons interact and such a description seems to fail. In contrast, the low-energy magnetic excitations are typically described in terms of fermionic spinons. Unfortunately, the latter quasiparticles are less intuitive, for they carry fractional quantum numbers and, most of the time, they also do interact.

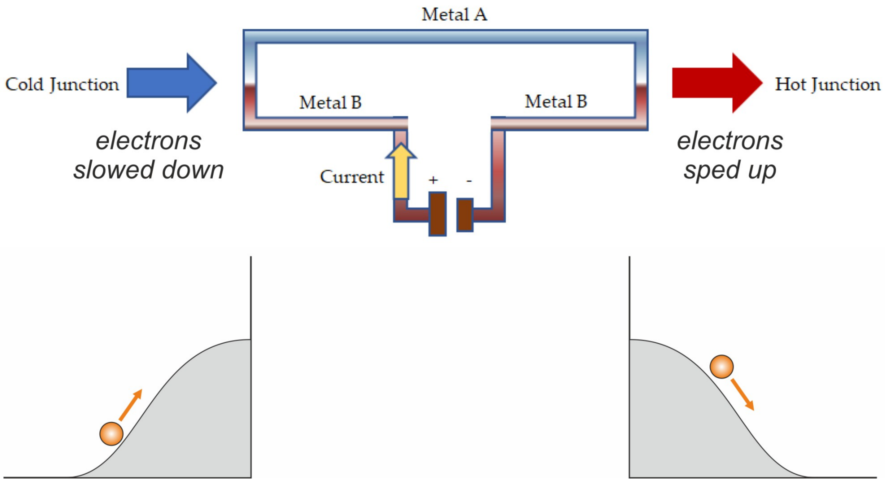
Material

Thermoelectrics

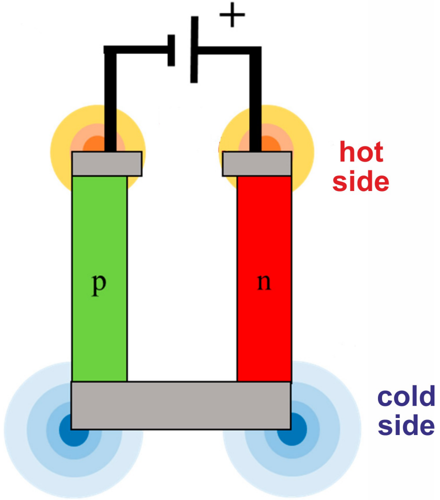

OMEGA HH501DK
022
TYPE K THERMOMETER


reference junction
thermocouple
measuring junction
metal A
metal B
voltmeter
Bunsen burner
mV

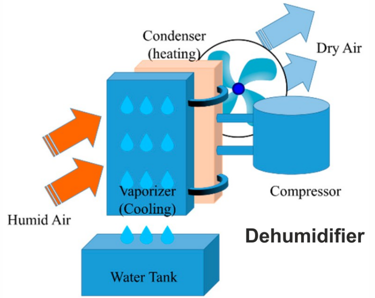

Type E
Type J
Type M
Type K
Type P
Type N
Type T
Au-Pt
Pt-Pd
$E(T)$ (mV)
Temperature T (deg C)
0
500
1000
1500
80
70
60
50
40
30
20
10
0



Electricity 2, 359 (2021)


+
p
n
hot side
cold side


USB beverage cooler


Condenser (heating)
Dry Air
Humid Air
Vaporizer (Cooling)
Compressor
Water Tank
Dehumidifier