Band structure

angle-resolved photoemission spectroscopy (ARPES)

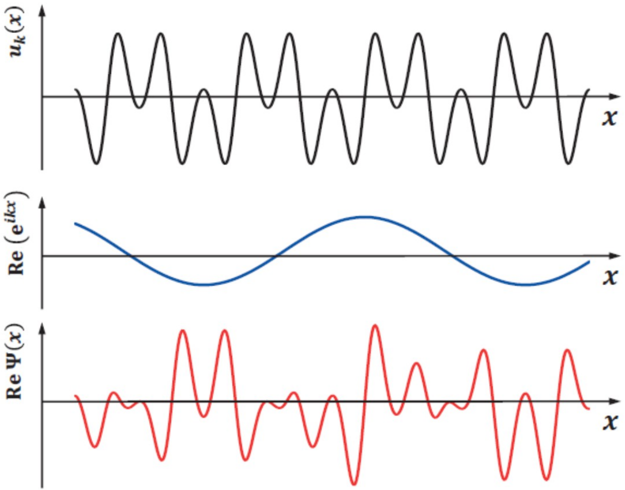
alkaline metals

Felix Bloch

by Alexander Tsirlin, Leipzig University

Lecture 19: December 14, 2023

Bloch wave



periodic part $u_{n\mathbf{k}}$

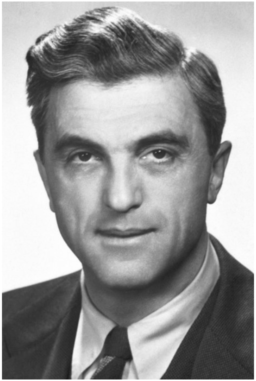
plane wave

Bloch wave

Gross and Marx, Festkörperphysik

Person

Felix Bloch



Felix Bloch
1905–1983

- 1924-1927: studied physics at ETH Zürich, with Peter Debye and Erwin Schrödinger
- 1927-1928: PhD in Leipzig with Werner Heisenberg

So, in October 1927 before the beginning of the winter semester, I left my nice home town for the first time, to arrive on a cold gray morning in that rather ugly city of Leipzig. The little room I found

Physics Today 29 (12), 23 (1976)

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It was an old building opposite a cemetery on one side and adjoining the garden of a mental institution on the other, but occupied by people who were far from being either dead or crazy.

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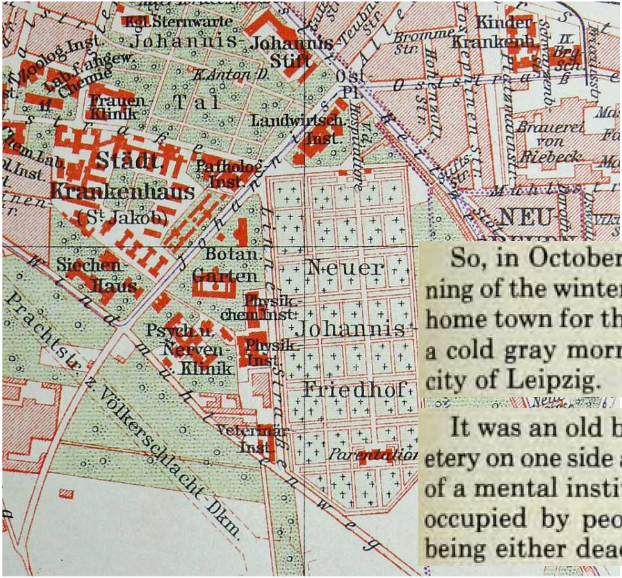

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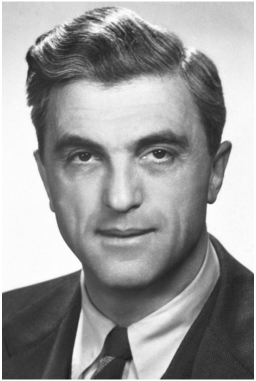
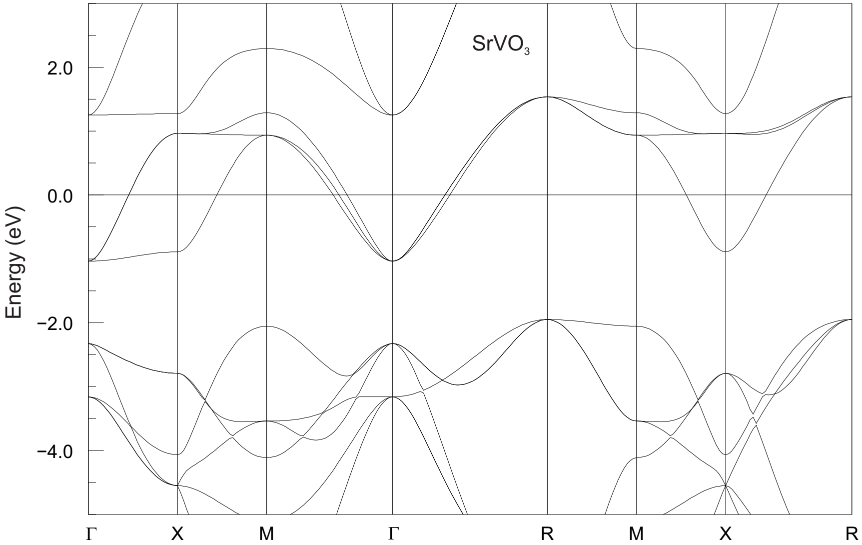


Felix Bloch

1905–1983

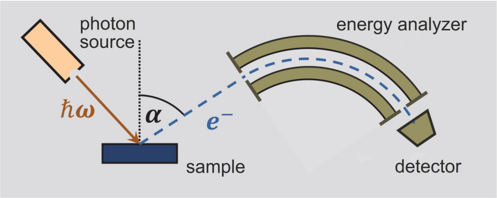
- 1924-1927: studied physics at ETH Zürich, with Peter Debye and Erwin Schrödinger
- 1927-1928: PhD in Leipzig with Werner Heisenberg
- early 1930's: work with Heisenberg on ferromagnetism, spin waves
- 1934: emigrated to the US started the faculty position at Stanford
- late 1930's: magnetic moment of neutron
- late 1940's: nuclear magnetization and nuclear magnetic resonance (NMR)
- 1952: Nobel Prize in Physics for NMR
- 1954–1961: first Director General at CERN

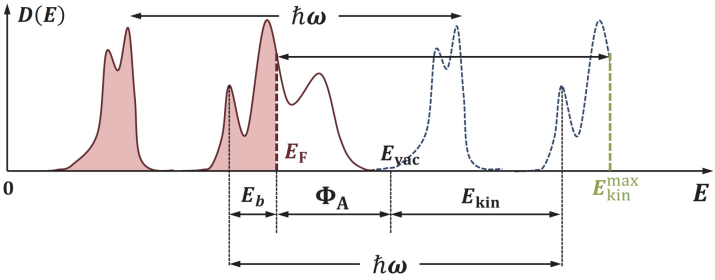

SrVO3
2.0
0.0
−2.0
−4.0
Energy (eV)
Γ
X
M
Γ
R
M
X
R

Experimental technique

photoemission spectroscopy

Gross and Marx, Festkörperphysik





UPS / XPS = ultraviolet / x-ray photoelectron spectroscopy

ARPES = angle-resolved photoemission spectroscopy

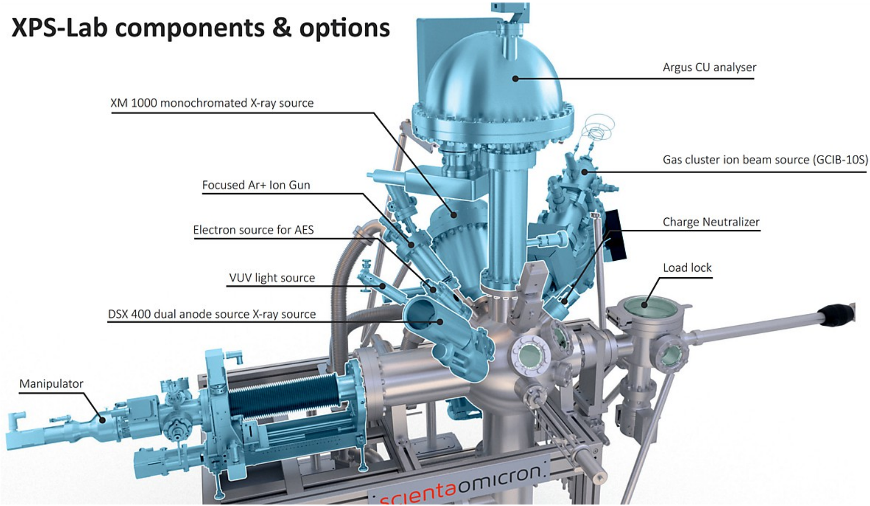


Image credit: scientaomicron.com (fair use)

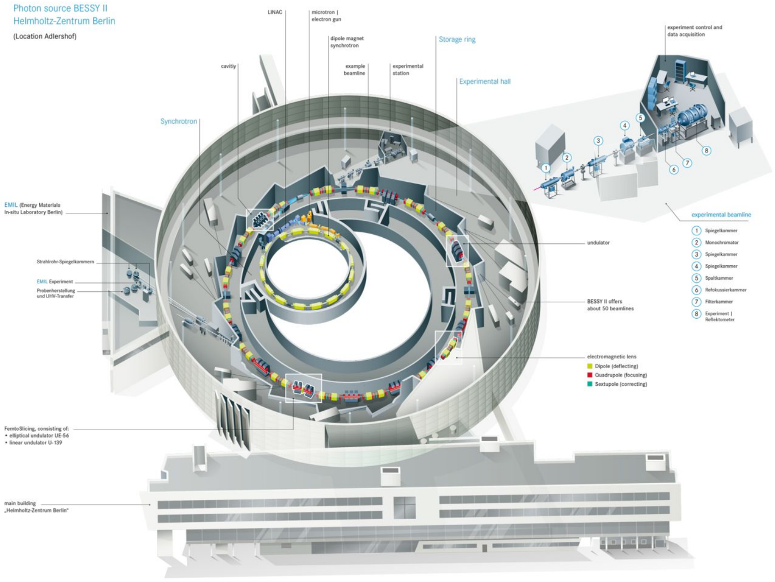


Image credit: Physikalisch-Technische Bundesanstalt (CC-BY-SA)

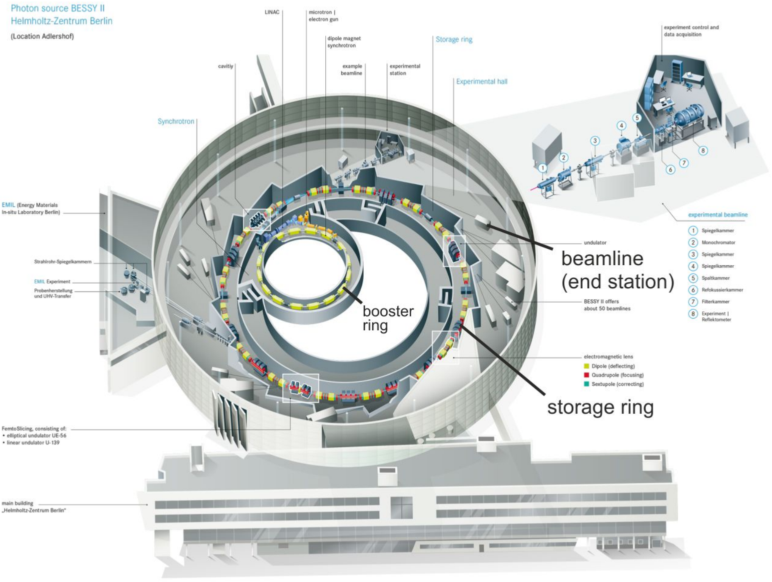
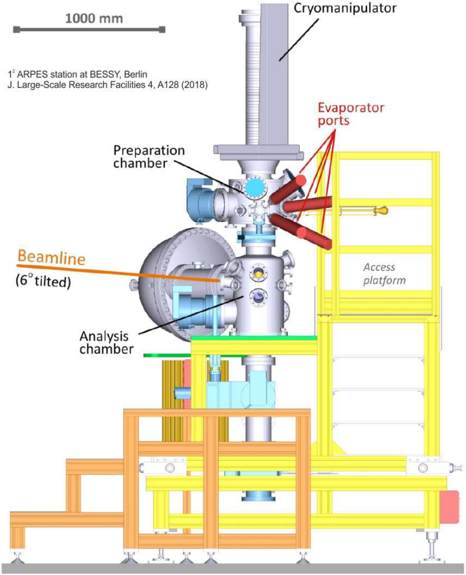
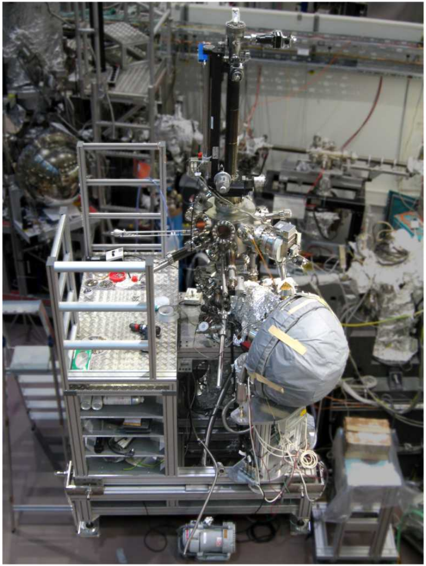
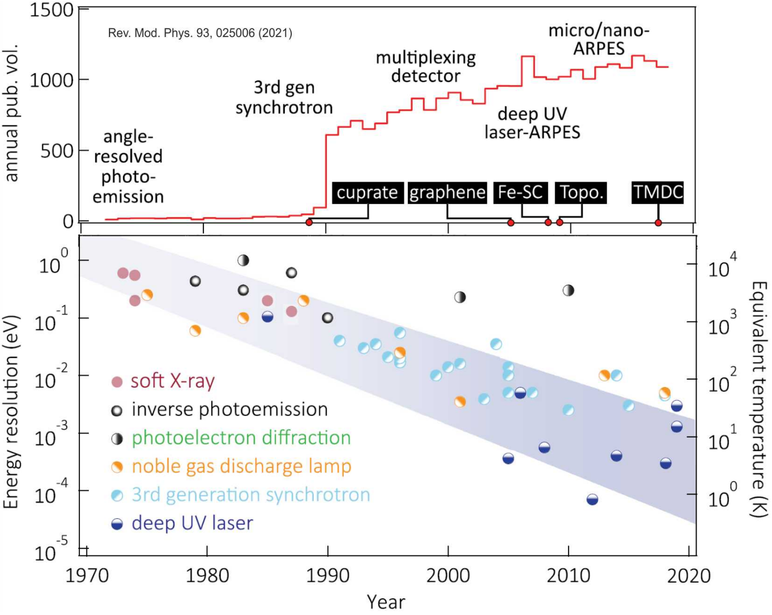


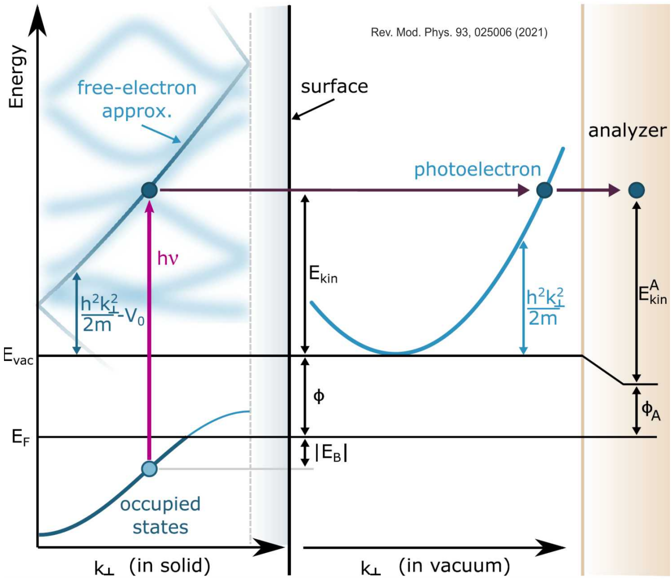
Image credit: Physikalisch-Technische Bundesanstalt (CC-BY-SA)


1000 mm
1[2] ARPES station at BESSY, Berlin
J. Large-Scale Research Facilities 4, A128 (2018)
Cryomanipulator
Evaporator ports
Preparation chamber
Beamline
(6° tilted)
Analysis chamber
Access platform

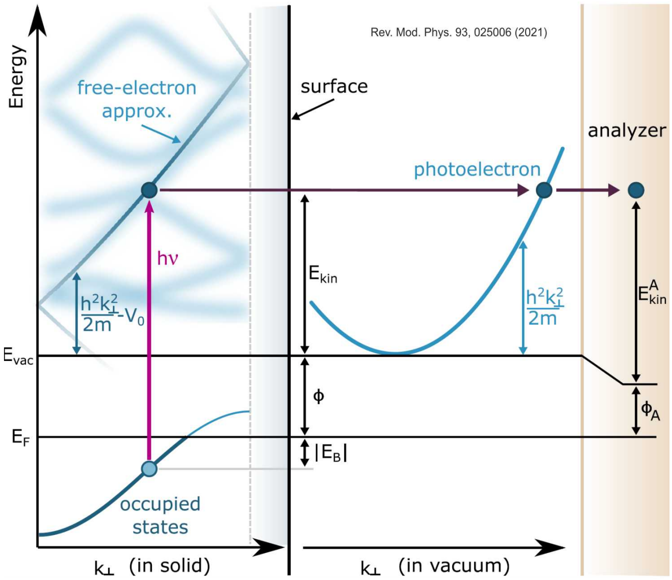


ARPES timeline





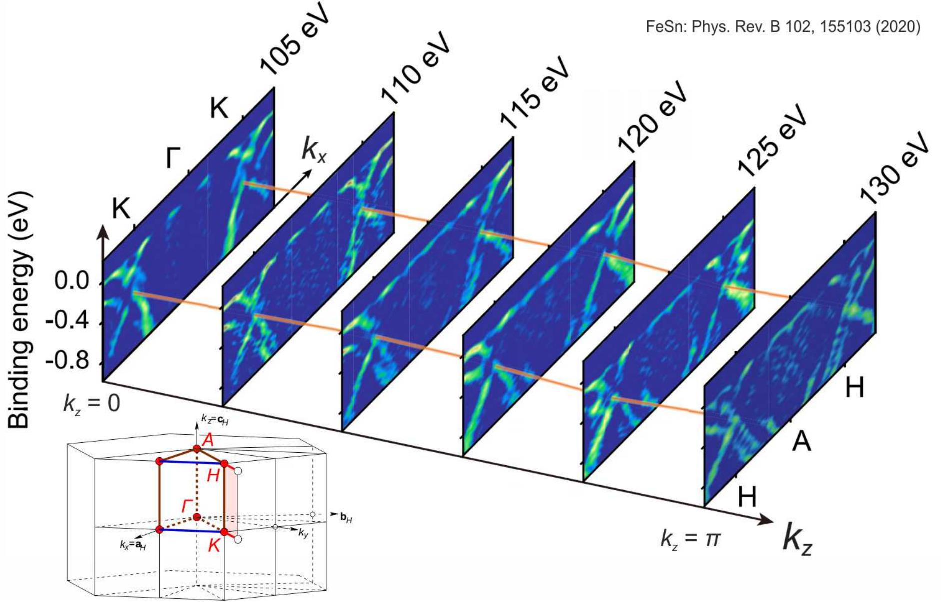
Photon energy $h\nu$ chooses k_z

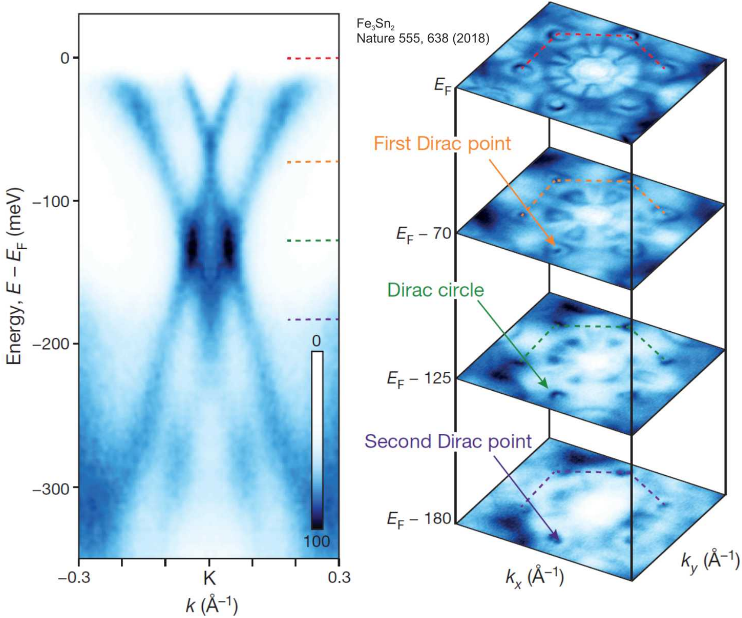


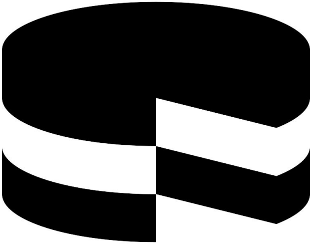
Photon energy $h\nu$ chooses k_z

Variable-energy photon source required

Synchrotron!

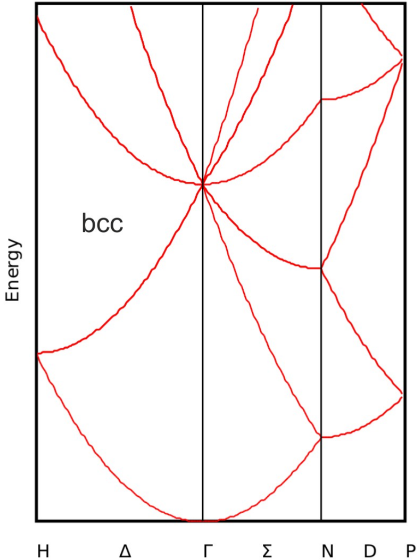

FeSn: Phys. Rev. B 102, 155103 (2020)
105 eV
110 eV
115 eV
120 eV
125 eV
130 eV
K
Γ
K
k_x
Binding energy (eV)
0.0
-0.4
-0.8
k_z = 0
H
A
H
k_z = π
k_z
k_z=$\mathbf{c}_H$
A
H
Γ
K
$\mathbf{b}_H$
k_y
k_x=$\mathbf{a}_H$

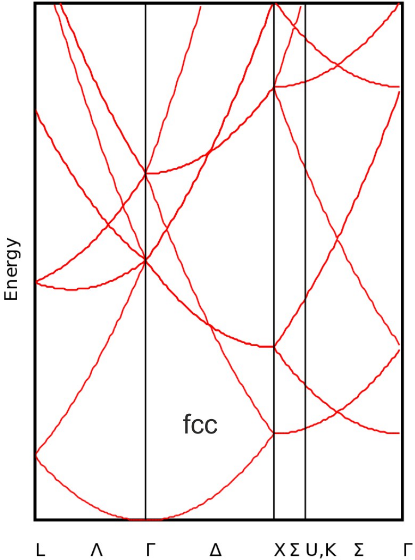

Fe3Sn2
Nature 555, 638 (2018)
Energy, E − EF (meV)
0
−100
−200
−300
−0.3
K
0.3
k (Å−1)
0
100
EF
First Dirac point
EF − 70
Dirac circle
EF − 125
Second Dirac point
EF − 180
kx (Å−1)
ky (Å−1)

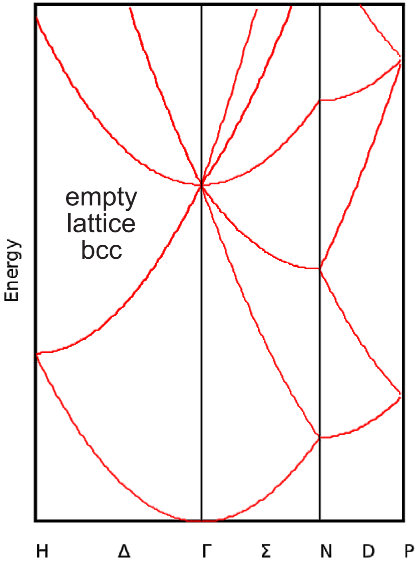


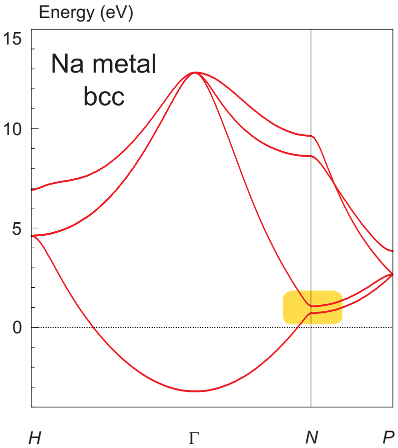
Material

alkaline metals


bcc
Energy
H Δ Γ Σ N D P


fcc
Energy
L Λ Γ Δ X Σ U,K Σ Γ


Energy
empty
lattice
bcc
H
Δ
Γ
Σ
N
D
P


Energy (eV)
15
10
5
0
Na metal
bcc
H
Γ
N
P

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.96	43 Tc -	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po -	85 At -	86 Rn -
87 Fr -	88 Ra -	89-103	104 Rf -	105 Db -	106 Sg -	107 Bh -	108 Hs -	109 Mt -	110 Ds -	111 Rg -							

BULK MODULI IN 10^{10} DYNES/CM^2 FOR SOME TYPICAL METALS[a]

METAL	FREE ELECTRON B	MEASURED B
Li	23.9	11.5
Na	9.23	6.42
K	3.19	2.81
Rb	2.28	1.92
Cs	1.54	1.43
Cu	63.8	134.3
Ag	34.5	99.9
Al	228	76.0

n_e decreases (Li → Cs)

Li–Cs: 1 valence electron

Al: 3 valence electrons

[a] The free electron value is that for a free electron gas at the observed density of the metal, as calculated from Eq. (2.37).

Ashcroft and Mermin, Solid State Physics

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n_e decreases (Li → Cs)

1 valence electron (Li, Na, K, Rb, Cs)

3 valence electrons (Al)

	Li	Na	K	Rb	Cs
T_{melting} (K)	454	371	336	312	301

Ashcroft and Mermin, Solid State Physics

Operating reactors
at nuclear power plants
in Russia, China, Japan

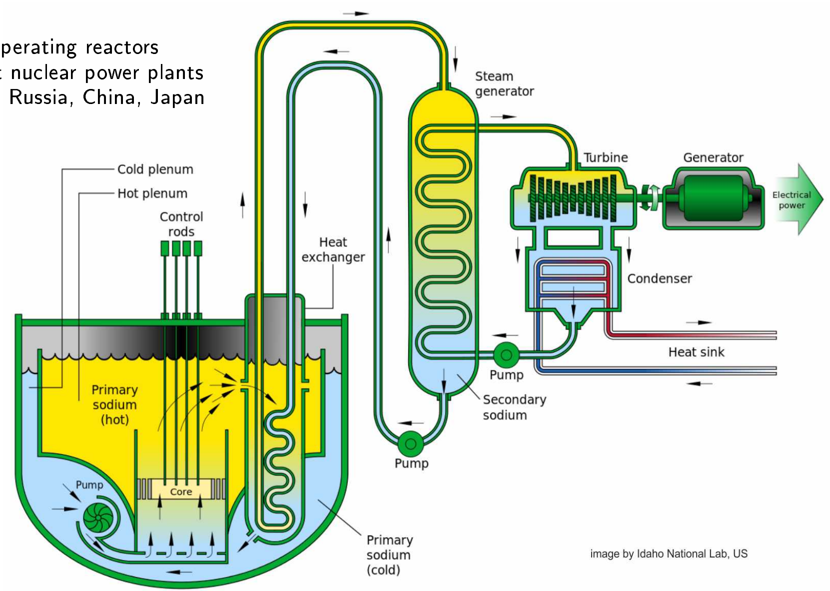
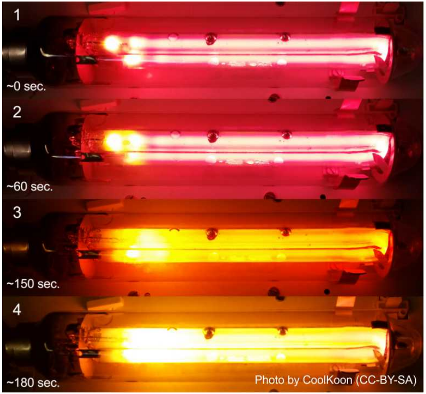
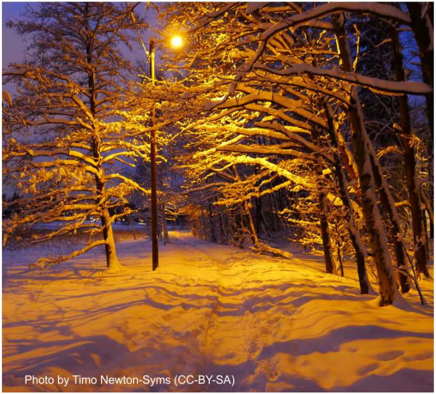


image by Idaho National Lab, US

Application: sodium lamps





Energy efficient but their light is nearly monochromatic (yellow)

Next lecture: 3.01.2024

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Exam:

- 6.02, 7.02, 8.02 (“early-bird” and previous years)
- 14.02 (special offer)
- 21.02, 22.02, 23.02... (regular)

  further information from the study office, around January 10

Exam questions: available on the web page

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Exam questions: available on the web page

Problem sheets: No. 9 available, No. 10 and 11 in January

you will know your final score around February 1

50% of the homework points remains a pre-requisite for the exam