

A Brief Tour of Physics: From Stars to Spin



Ariel Paul



University of Colorado **Boulder**

What is **Physics**?

Our **functional definition**:

Discovering and applying a model of a physical system, formalized in mathematics, to predict its past and future behavior.

Stars (Night Sky)

- **Inspiration!**
- Predictable motion



Motion (Kinematics)

- First model: **point masses**

- Equation of motion:

$$x(t) = A \sin(\omega t + \varphi)$$

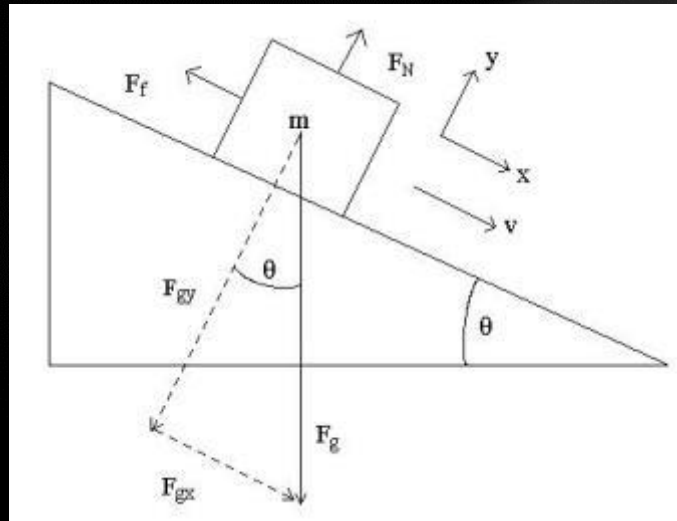
- Extend to rigid bodies (angular velocity etc.)

What Causes Motion?

Newtonian view: **forces**

$$\vec{F}_{net} = m\vec{a}$$

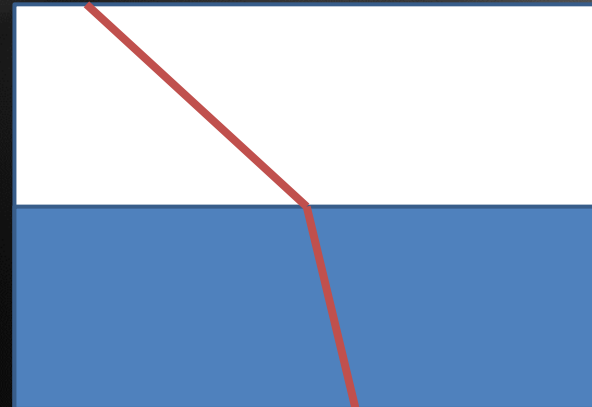
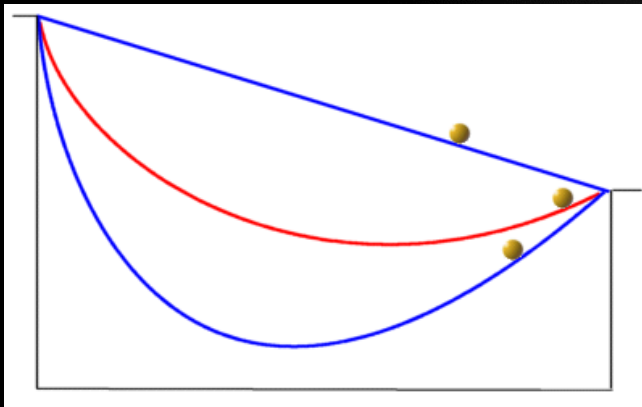
Implies **conservation of momentum** ($m\vec{v}$)



Conservation of Energy

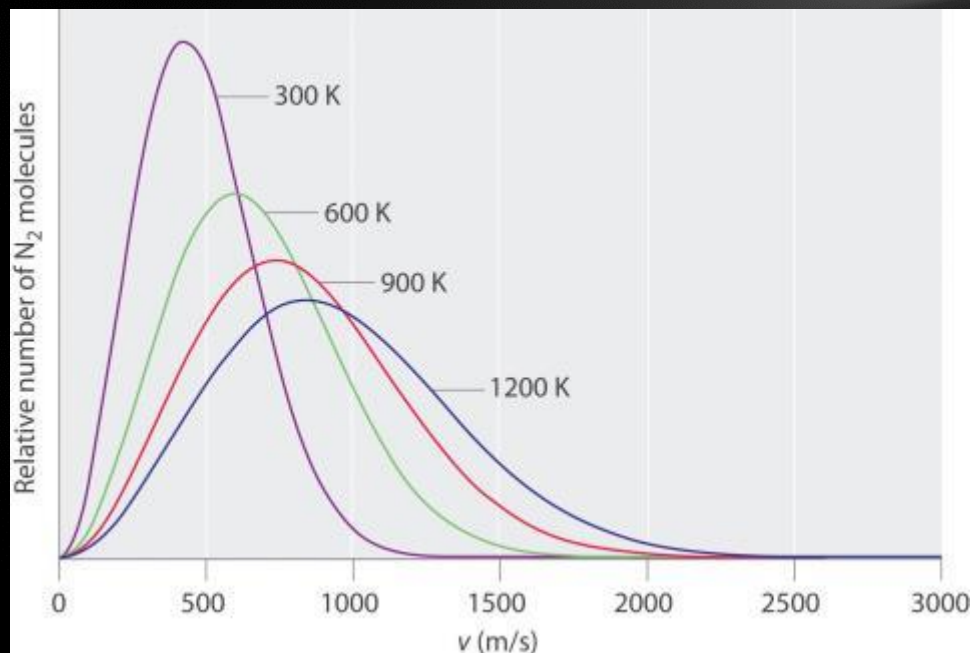
- Total energy of a closed system constant
- Energy in motion or potential energy (field)
- **No** direct energy meter!

Lagrangian View: Minimize **Action**



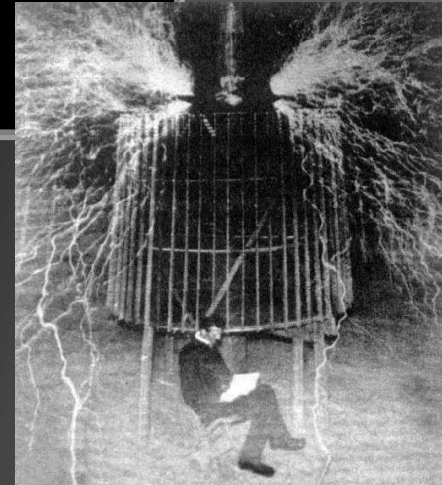
Statistical Mechanics

- Using micro to understand macro
- **Large** numbers of particles
- Probabilities become “laws”

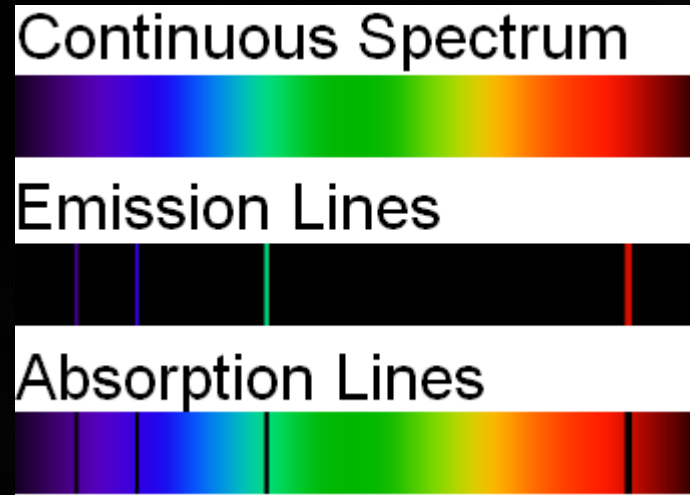


Electricity and Magnetism

- **Charges** → electric forces, field
- Moving charges → magnetic forces
- Electric current → magnetic field
- Changing magnetic field → electric field
- Light is electromagnetic **wave**

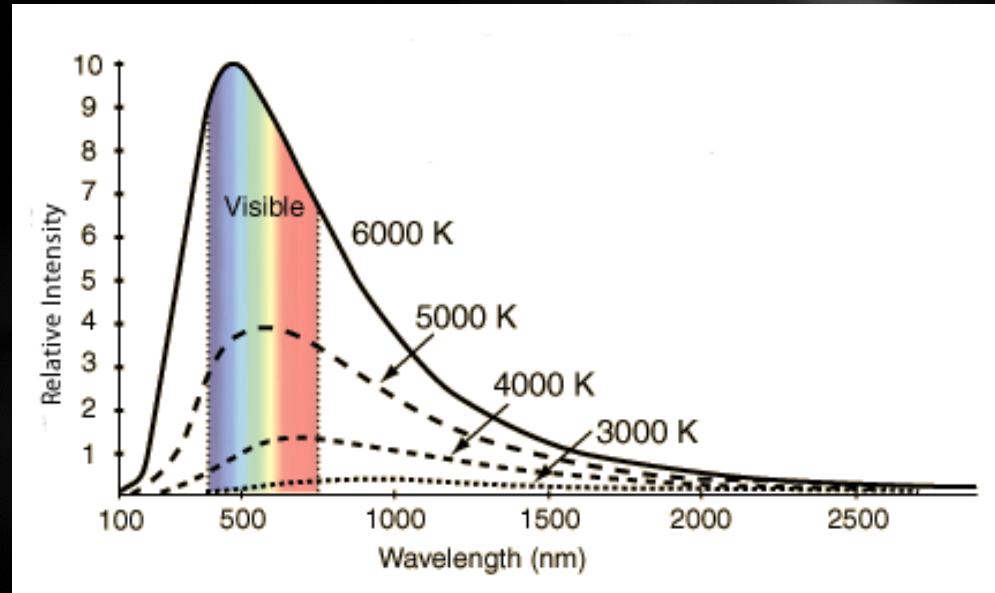
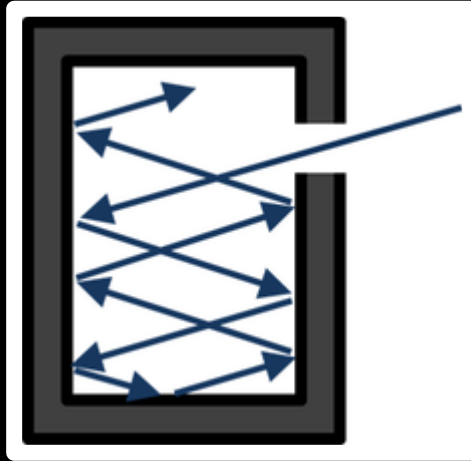


Spectroscopy



- Every element has a **unique** spectra
- Atoms can emit or absorb light
- **Amazing** tool for discovery!!

Blackbody Conundrum



- Shorter wavelengths, more should fit??
- Classical physics prediction incorrect
- “Ultraviolet **catastrophe**”

Quantization

Planck's Trick: $E = hf$

Energy weighted by frequency (color)

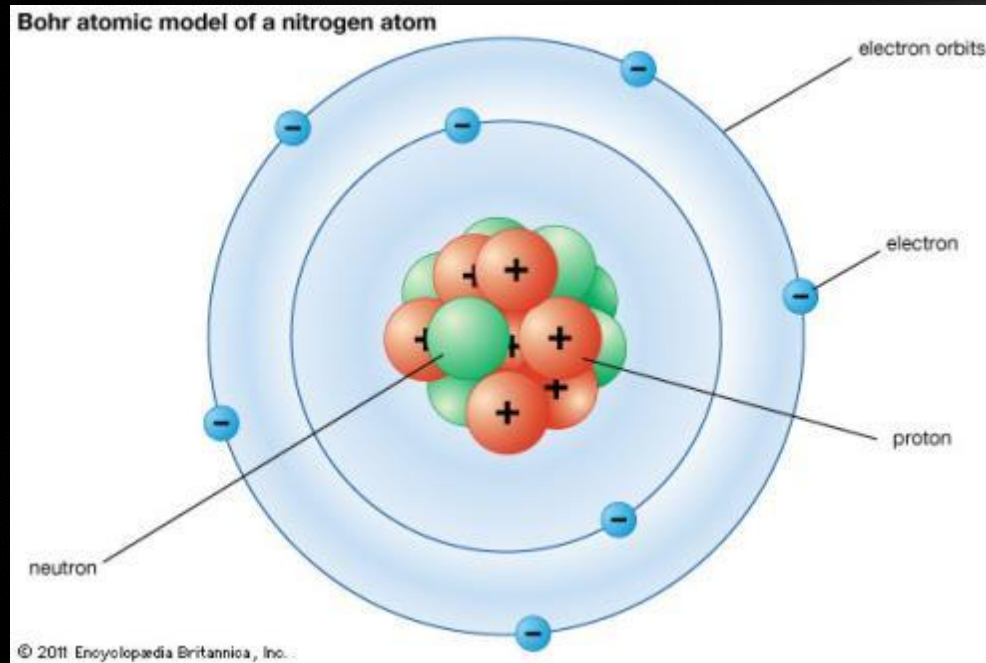


Box analogy:

Fill box with balls of different density to obtain specific weight

Bohr Model

- Quantized energy levels
- Helps explain atomic spectra



Pauli Exclusion and Spin

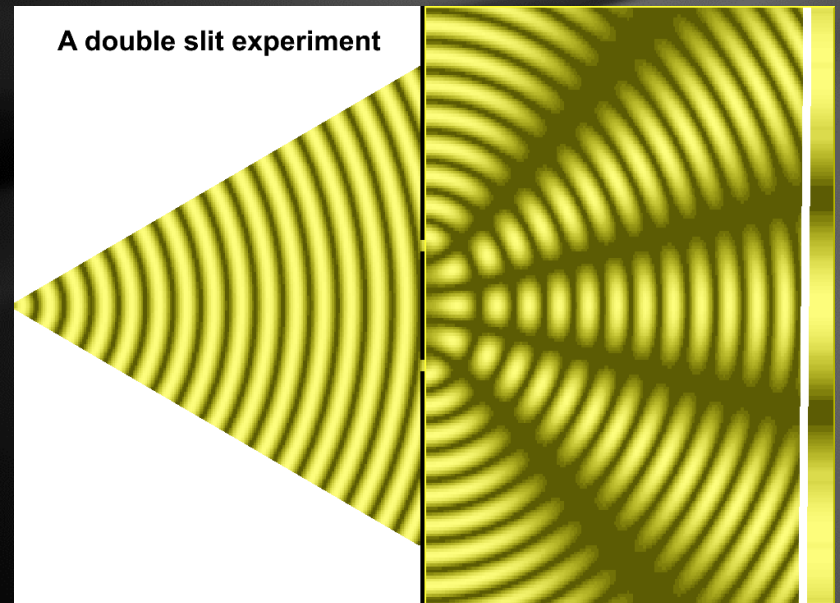
Spin: “intrinsic” angular momentum



Bosons: integer \rightarrow the wave

Waves and Interference

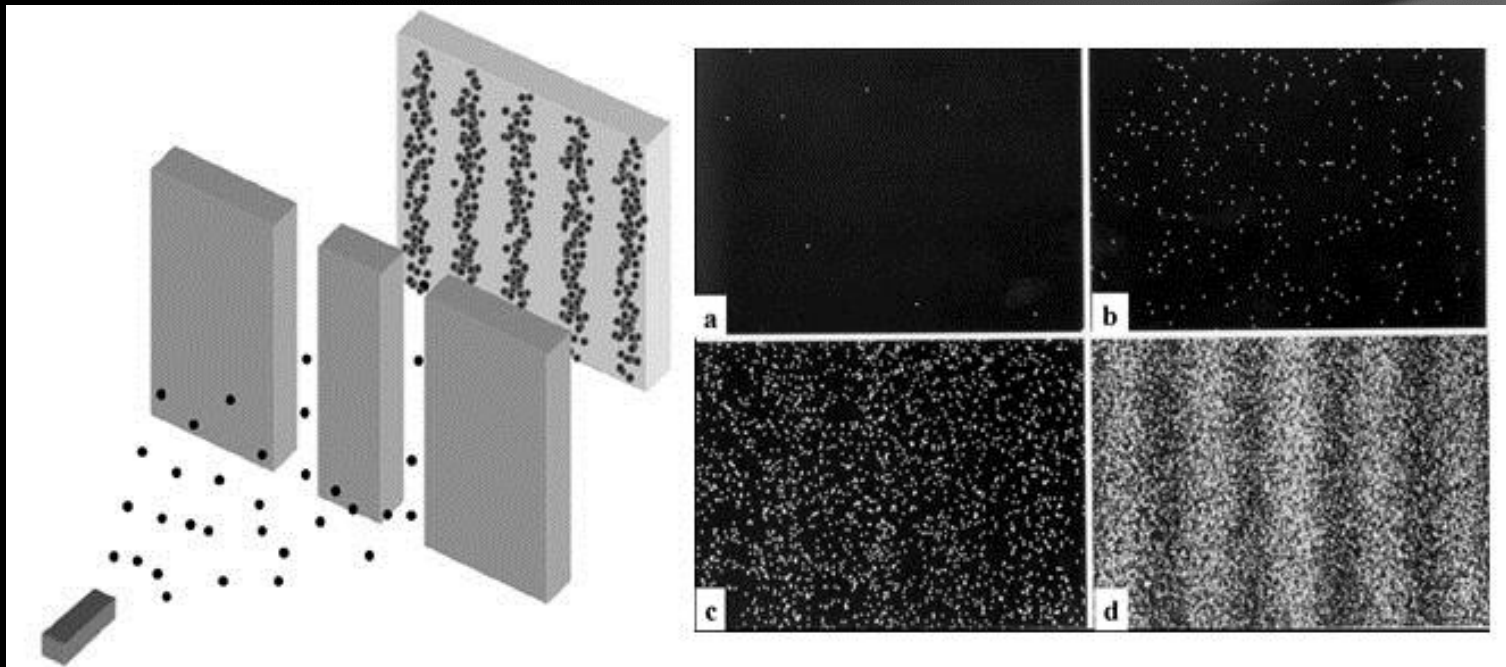
Hallmark of a wave is **interference**



Wave vs. Particle

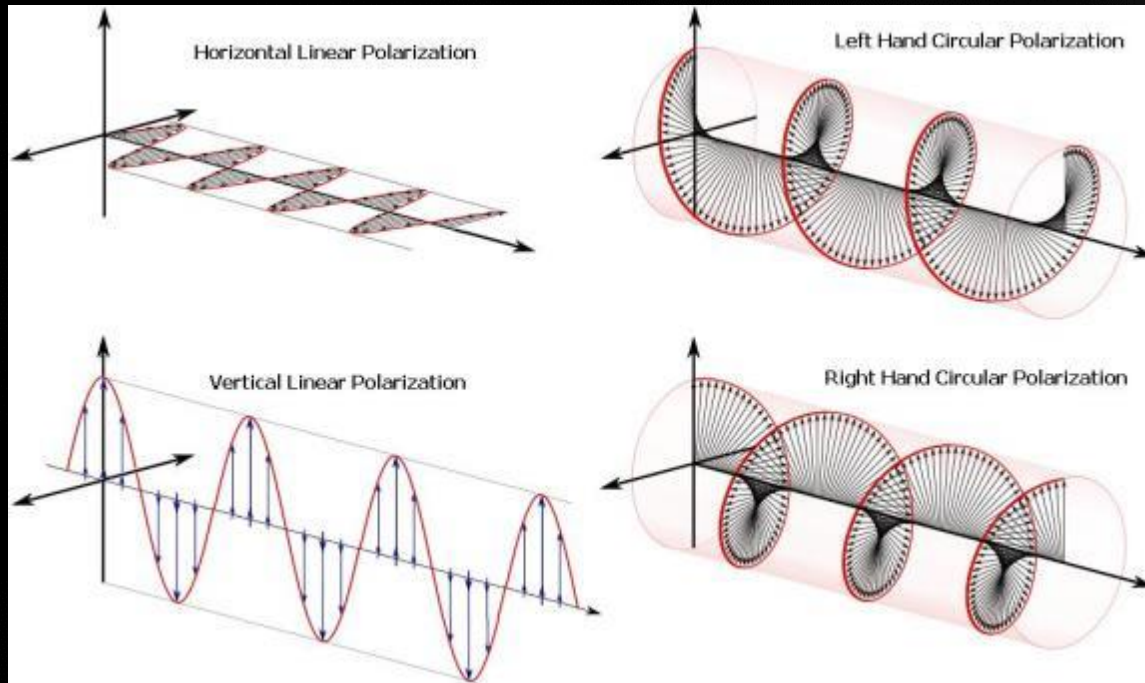
$$p \sim \frac{1}{\lambda}$$

Matter (like electrons) exhibits **interference**



What is Waving?

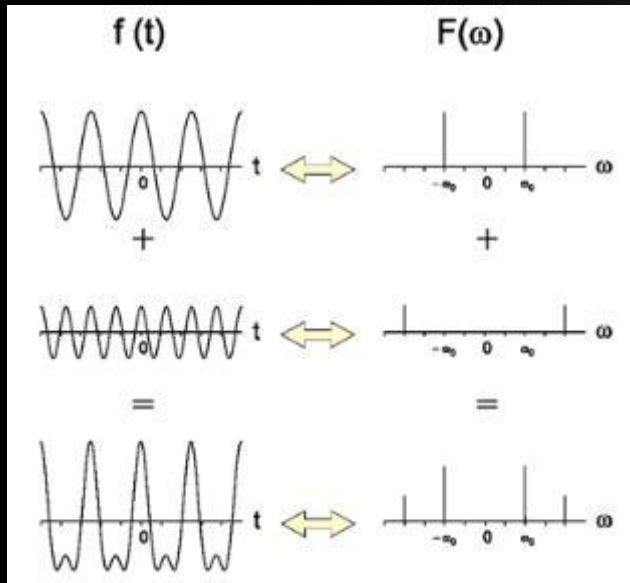
A **probability** amplitude of (often) mixed states



Observation “collapses” the wavefunction

Uncertainty Relations

- Spread in time – peaked in frequency
- Peaked in time – spread in frequency
- **Analogous** to position and momentum



Heisenberg:
 $\Delta p \Delta x \sim \hbar$

You **Are** Star Dust!

All elements above lithium baked in stars, released in supernova!!



The Periodic Table of the Elements

3	Li
Lithium	6.94
3	Li

Atomic Number

Element Symbol

Element Name

Average Atomic Mass

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 101.07	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.91	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97	
87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	103 Lr Lawrencium 260	104 Rf Rutherfordium 261	105 Db Dubnium 262	106 Sg Seaborgium 266	107 Bh Bohrium 264	108 Hs Hassium 277	109 Mt Meitnerium 268	110 Ds Darmstadtium 285	111 Rg Roentgenium 281	112 Cn Copernicium 285					
89 Ce Cerium 140.12	90 Pr Praseodymium 140.91	91 Nd Neodymium 144.24	92 Pm Promethium 144.91	93 Sm Samarium 150.36	94 Eu Europium 151.96	95 Gd Gadolinium 157.25	96 Tb Terbium 158.93	97 Dy Dysprosium 162.50	98 Ho Holmium 164.93	99 Er Erbium 167.26	100 Tm Thulium 168.93	101 Yb Ytterbium 173.05	102 Lu Lutetium 174.97				
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendelevium 288	102 No Nobelium 289	103 Lr Lawrencium 260				