History's Most Significant Technological Breakthroughs

17th and 18th Centuries: Classical Newtonian physics $\Rightarrow$ engineering $\Rightarrow$ buildings, bridges, cars, trains, planes, rockets, . . .

19th Century: Heat engines, electrical power generation, and EM waves $\Rightarrow$ control of power $\Rightarrow$ industrial revolution and communications revolution.

20th Century: Quantum mechanics and semiconductors $\Rightarrow$ the modern digital age, including computers, cell phones, ... Today's class!

21st Century: That's up to you!

Possibilities: Quantum nanotechnology, biotechnology, quantum computing (Thursday's Class), . . .

The 3-D Schrödinger Equation

$$-\frac{\hbar^2}{2m}\left[\frac{\partial^2\psi}{\partial r^2}+\frac{2}{r}\frac{\partial\psi}{\partial r}+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\psi}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2\psi}{\partial\phi^2}\right]+U\psi=E\psi$$

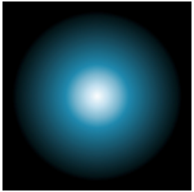
For hydrogen: $U=\dfrac{kq_1q_2}{r}=-\dfrac{ke^2}{r}$ (remember Unit 1!)

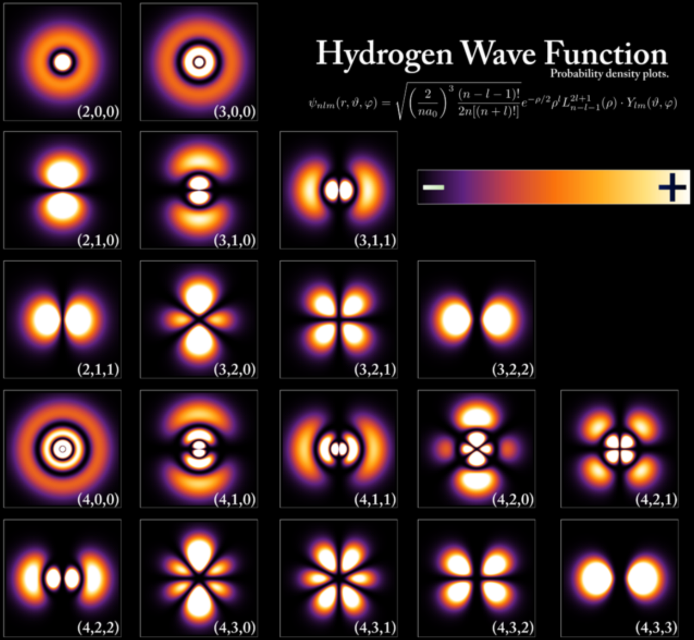
	n	ℓ	m_ℓ	$\psi_{n\ell m_\ell}(r,\theta,\phi)$
1s	1	0	0	$\frac{1}{\sqrt{\pi a_0^3}}\,e^{-r/a_0}$
2s	2	0	0	$\frac{1}{4\sqrt{2\pi a_0^3}}\left[2-\frac{r}{a_0}\right]e^{-r/2a_0}$
2p	2	1	0	$\frac{1}{4\sqrt{2\pi a_0^3}}\,\frac{r}{a_0}\,e^{-r/2a_0}\,\cos\theta$
2p	2	1	±1	$\frac{1}{8\sqrt{\pi a_0^3}}\frac{r}{a_0}\,e^{-r/2a_0}\,\sin\theta\, e^{\pm i\phi}$

$a_0=\frac{\hbar^2}{me^2}=0.0529$ nm

Probability density is $|\psi|^2$

For 1s orbital:

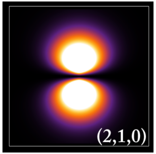




Hydrogen Wave Function
Probability density plots.
$\psi_{nlm}(r,\vartheta,\varphi) = \sqrt{\left(\frac{2}{na_0}\right)^3 \frac{(n-l-1)!}{2n[(n+l)!]}}\, e^{-\rho/2}\rho^l L^{2l+1}_{n-l-1}(\rho)\cdot Y_{lm}(\vartheta,\varphi)$
−
+
(2,0,0)
(3,0,0)
(2,1,0)
(3,1,0)
(3,1,1)
(2,1,1)
(3,2,0)
(3,2,1)
(3,2,2)
(4,0,0)
(4,1,0)
(4,1,1)
(4,2,0)
(4,2,1)
(4,2,2)
(4,3,0)
(4,3,1)
(4,3,2)
(4,3,3)

Lecture 19 — Concept Test 1

The probability density for the 2p state is shown at right. What does this mean about the electron orbiting the nucleus?



1. The electron orbits the nucleus in a circular orbit
2. The electron orbits the nucleus in an elliptical orbit
3. The electron precesses as it orbits the nucleus
4. The electron's orbit is unstable and changes each time it circles around the nucleus
5. You can't think of the electron as orbiting in any classical sense

Lecture 19 — Concept Test 2

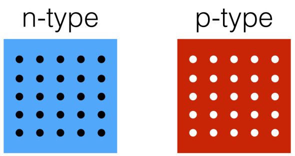
How many possible quantum states can an electron in the hydrogen atom with $n = 2$ have?

1. 2
2. 4
3. 6
4. 8
5. 10
6. 12

Group→ ↓Period	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc		22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y		40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
				*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
				**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Lecture 19 — Concept Test 3

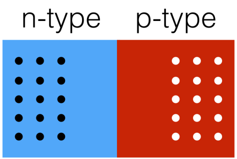
You have two isolated doped semi-conductors (not in contact with one another). Which of the following is true?



1. The p-type has a net positive charge and the n-type has a net negative charge
2. The n-type has a net positive charge and the p-type has a net negative charge
3. Both the p-type and n-type are uncharged

Lecture 19 — Concept Test 4

We now bring the two semiconductors into contact, creating a depletion zone near the boundary between them. Which of the following is true?



1. The p-type has a net positive charge and the n-type has a net negative charge
2. The n-type has a net positive charge and the p-type has a net negative charge
3. Both the p-type and n-type are uncharged