

Welcome to 3.091

Lecture 6

September 21, 2009

Particle-Wave Duality

3.091 Periodic Table Quiz

1																	2
3	4											5	6	7	8	9	10
11	12											13	14	15	16	17	18
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
87	88	89															

Name _____

Grade _____ /10

n	l	Subshell Designation	m_l	Number of Orbitals in Subshell	Number of Orbitals in Shell
1	0	1s	0	1	1
2	0	2s	0	1	4
	1	2p	-1, 0, 1	3	
3	0	3s	0	1	9
	1	3p	-1, 0, 1	3	
	2	3d	-2, -1, 0, 1, 2	5	
4	0	4s	0	1	16
	1	4p	-1, 0, 1	3	
	2	4d	-2, -1, 0, 1, 2	5	
	3	4f	-3, -2, -1, 0, 1, 2, 3	7	

Values of n , l , and m , through $n = 4$

1 IA IA																	18 VIII 0																																																							
1.00794 -259.34 -252.87 0.0899 2.20 13.598 5.392 [He]2s ¹ Lithium Hydrogen																	4,002602 -272.236 am -268.93 0.1785 - 24.587 1s ² Helium																																																							
6.941 180.5 1342 0.534 0.98 5.392 [He]2s ¹ Lithium Hydrogen	3 1 1 1 1 1 1															2 1 1																																																								
9.012182 1287 2471 1.8477 1.57 9.222 [He]2s ² Beryllium	4 2 2 2 2 2 2																	10 18 18																																																						
22.989768 97.72 883 0.97 0.93 5.139 [Ne]3s ¹ Sodium	11 2 2 2 2 2 2	24.3050 650 1090 1.74 7.646 [Ne]3s ² Magnesium													17 17 17 17 17 17 17	18 18 18 18 18 18 18																																																								
39.0983 63.38 759 0.86 0.82 4.341 [Ar]4s ¹ Potassium	19 2 2 2 2 2 2	40.078 842 1484 1.54 1.00 6.113 [Ar]3d ⁴ Titanium	20 2 2 2 2 2 2	44.955910 1591 2830 2.989 1.31 7.646 [Ar]3d ² Titanium	21 2 2 2 2 2 2	47.88 16.8 3287 4.5 1.36 6.82 [Ar]3d ² Titanium	22 2 2 2 2 2 2	50.9415 1910 3407 5.96 1.66 7.66 [Ar]3d ² Chromium	23 2 2 2 2 2 2	51.9961 1907 3287 5.96 1.66 7.66 [Ar]3d ² Chromium	24 2 2 2 2 2 2	54.93805 1246 2061 7.47 1.55 7.870 [Ar]3d ⁵ Manganese	25 2 2 2 2 2 2	55.847 1538 2861 7.86 1.83 7.376 [Ar]3d ⁵ Iron	26 2 2 2 2 2 2	58.93320 1495 2927 8.92 1.91 7.26 [Ar]3d ⁶ Cobalt	27 2 2 2 2 2 2	58.6934 1455 2913 8.90 1.91 7.394 [Ar]3d ⁷ Nickel	28 2 2 2 2 2 2	63.546 1084.62 907 8.94 1.90 7.576 [Ar]3d ⁹ Copper	29 2 2 2 2 2 2	65.39 419.53 2204 6.095 1.81 5.999 [Ar]3d ¹⁰ Zinc	30 2 2 2 2 2 2	69.723 29.76 2204 6.095 1.81 5.999 [Ga]3d ¹⁰ Gallium	31 2 2 2 2 2 2	72.61 938.25 2833 5.35 2.01 7.899 [Ar]3d ¹⁰ Zinc	32 2 2 2 2 2 2	74.92159 8177P 2833 5.7275°C 2.18 9.81 [Ar]3d ¹⁰ Arsenic	33 2 2 2 2 2 2	78.96 221 2852 4.81 2.01 9.81 [Ar]3d ¹⁰ Selenium	34 2 2 2 2 2 2	83.80 7.2 -2.4,6 3.19 2.96 9.752 [Ar]3d ¹⁰ Bromine	35 2 2 2 2 2 2	85.47 -7.2 -1.5,5,7 3.19 2.96 9.752 [Ar]3d ¹⁰ Krypton	36 2 2 2 2 2 2	88.90 -157.36 -152.22 3.74 1.784 9.399 [Ar]3d ¹⁰ Rubidium	37 2 2 2 2 2 2	87.62 1582 3336 2.6 0.95 5.695 [Kr]4d ⁵ Strontium	38 2 2 2 2 2 2	88.90585 1526 3409 4.469 1.22 6.84 [Kr]4d ⁵ Zirconium	39 2 2 2 2 2 2	91.224 1855 3409 4.5 1.33 6.84 [Kr]4d ⁵ Zirconium	40 2 2 2 2 2 2	92.90638 2477 4474 7.44 1.6 7.099 [Kr]4d ⁵ Molybdenum	41 2 2 2 2 2 2	95.94 2623 4639 10.2 2.16 7.099 [Kr]4d ⁵ Niobium	42 2 2 2 2 2 2	(97.9072) 2157 4265 12.3 2.2 7.28 [Kr]4d ⁵ Rhenium	43 2 2 2 2 2 2	101.07 2334 710 12.4 2.2 7.46 [Kr]4d ⁵ Ruthenium	44 2 2 2 2 2 2	102.90550 1964 3695 12.4 2.2 8.34 [Kr]4d ⁵ Rhodium	45 2 2 2 2 2 2	106.42 1554.9 2963 12.02 1.93 7.576 [Kr]4d ¹⁰ Palladium	46 2 2 2 2 2 2	107.8582 961.78 2162 8.642 1.69 7.576 [Kr]4d ¹⁰ Silver	47 2 2 2 2 2 2	112.411 321.07 767 8.642 1.69 7.576 [Kr]4d ¹⁰ Cadmium	48 2 2 2 2 2 2	114.818 156.60 2072 6.842°C 1.78 8.641 [Kr]4d ¹⁰ Tin	49 2 2 2 2 2 2	118.710 631.63 1587 6.842°C 2.05 8.641 [Kr]4d ¹⁰ Antimony	50 2 2 2 2 2 2	127.60 449.51 2602 9.88 6.25 9.009 [Kr]4d ¹⁰ Tellurium	51 2 2 2 2 2 2	127.757 113.7 1587 6.842°C 2.05 8.641 [Kr]4d ¹⁰ Iodine	52 2 2 2 2 2 2	127.60 449.51 2602 9.88 6.25 9.009 [Kr]4d ¹⁰ Tellurium	53 2 2 2 2 2 2	126.90447 184.4 1587 6.842°C 2.05 8.641 [Kr]4d ¹⁰ Iodine	54 2 2 2 2 2 2	131.29 111.75 108.04 5.1,5.7 1.84 9.73 [Kr]4d ¹⁰ Xenon

* 140.115 799 3510 6.770 1.13 5.466 [Xe]4f ¹⁵ d ¹ Cerium	58 3,4	140.90765 931 3066 6.773 1.00 5.422 [Xe]4f ¹⁶ Praseodymium	59 3,4	144.24 1016 3106 7.00 1.14 5.489 [Xe]4f ¹⁶ Neodymium	60 3	(144.9127) 1042 3002 7.254 1.13 5.554 [Xe]4f ¹⁶ Promethium	61 3	150.36 1072 3190 7.536 1.17 5.631 [Xe]4f ¹⁶ Samarium	62 2,3	151.965 822 1596 5.244 1.2 5.666 [Xe]4f ¹⁶ Europium	63 3,4	157.25 1314 3221 7.901 1.20 5.842 [Xe]4f ¹⁶ Gadolinium	64 3,4	158.92534 1359 3221 8.230 1.2 5.842 [Xe]4f ¹⁶ Terbium	65 3,4	162.50 1411 2561 8.80 1.22 6.018 [Xe]4f ¹⁶ Dysprosium	66 3	164.93032 1472 2694 9.066 1.24 6.101 [Xe]4f ¹⁶ Holmium	67 3	167.26 1529 2862 9.066 1.24 6.101 [Xe]4f ¹⁶ Erbium	68 3	168.93421 1545 3196 9.321 1.23 6.1846 [Xe]4f ¹⁶ Thulium	69 2,3	173.04 824 1194 6.966 1.1 6.25394 [Xe]4f ¹⁶ Ytterbium	70 2,3 3	174.967 1663 3393 9.84 1.27 5.42589 [Xe]4f ¹⁶ Lutetium	
** 232.0381 1750 4788 11.72 1.3 6.08 [Rn]5f ¹⁴ Thorium	90 4	231.03588 1572 4131 15.37 1.5 5.89 [Rn]5f ¹⁴ Protactinium	91 4,5	238.0289 1135 1905+02 4131 1.38 6.05 [Rn]5f ¹⁴ Uranium	92 3,4,5,6	(237.0482) 644 3228 19.816 1.3 6.19 [Rn]5f ¹⁴ Neptunium	93 3,4,5,6	(244.0642) 644 3228 19.816 1.28 5.8 [Rn]5f ¹⁴ Plutonium	94 3,4,5,6	(247.0614) 640 2507 13.45 1.3 6.02 [Rn]5f ¹⁴ Americium	95 3,4,5,6	(247.0703) 1345 3145 14.78 1.3 6.02 [Rn]5f ¹⁴ Curium	96 3	(247.0703) 1050 3293 14.78 1.3 6.02 [Rn]5f ¹⁴ Berkelium	97 3,4	(251.0796) 900 3350 16.50 1.3 6.42 [Rn]5f ¹⁴ Californium	98 3	(252.083) 860 3370 16.50 1.3 6.42 [Rn]5f ¹⁴ Einsteinium	99 3	(257.0951) 1327 3590 16.50 1.3 6.42 [Rn]5f ¹⁴ Fermium	100 3	(258.10) 827 3627 16.50 1.3 6.42 [Rn]5f ¹⁴ Mendelevium	101 2,3	(259.1009) 827 3627 16.50 1.3 6.42 [Rn]5f ¹⁴ Nobelium	102 2,3	(252.11) 827 3627 16.50 1.3 6.42 [Rn]5f ¹⁴ Lawrencium	103 3

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electronic
configuration

12.011

4492TP

3825SP

2.25

2.55

11.260

$[\text{He}]2s^2p^2$

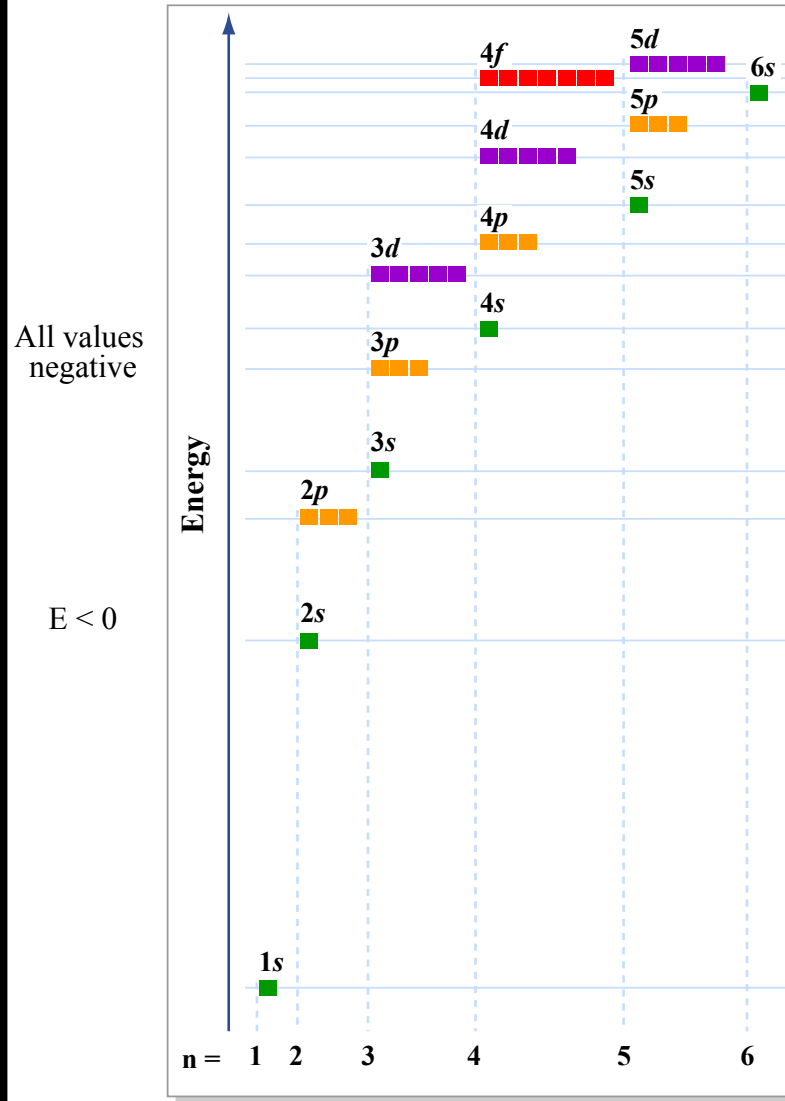
Carbon

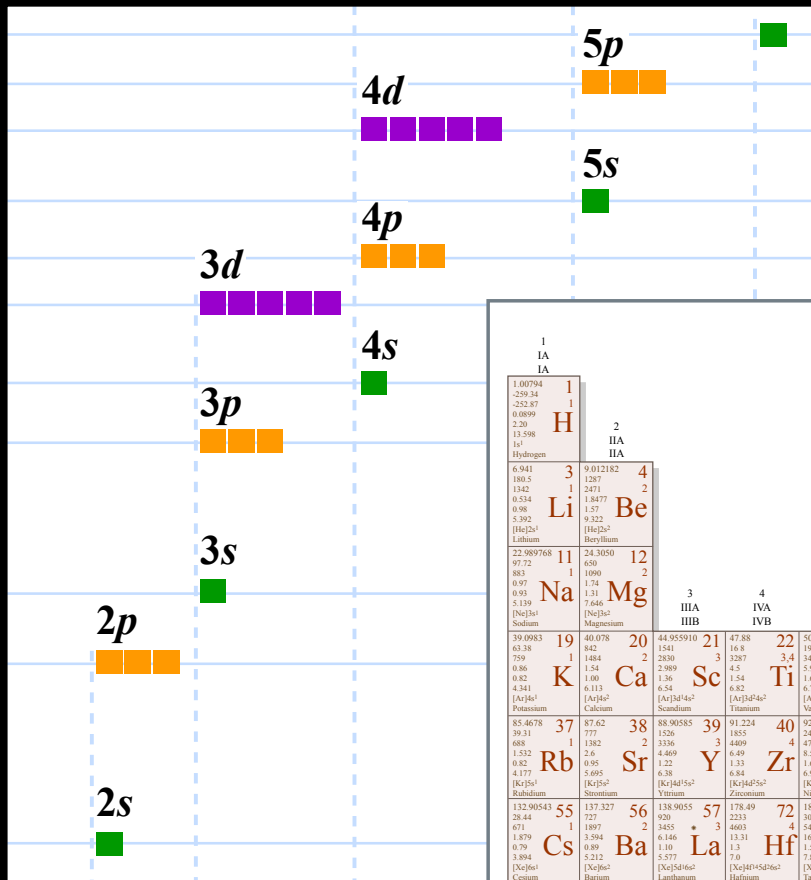
6

2, \pm 4

C

Principal shells





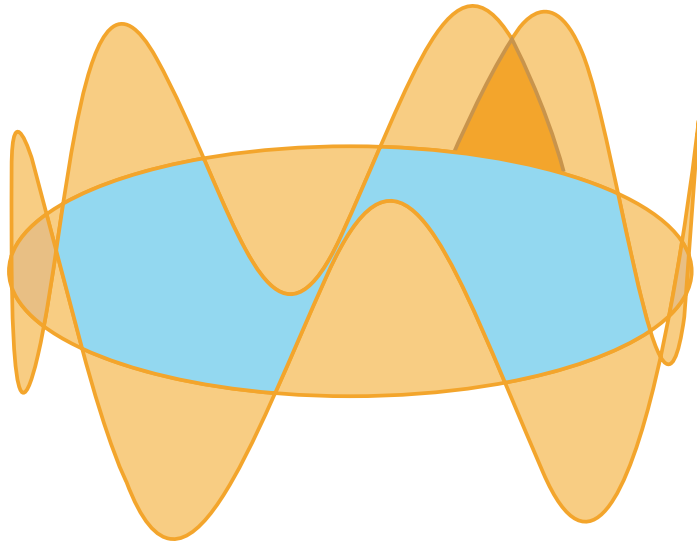
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1.00794 1.00784 252.87 0.0899 2.20 11.588 41	H										4.002602 232.036 -268.93 0.1785	2	He																							
6.941 180.5 1342 0.534 0.98 5.982	9.012182 1287 2471 1.8477 1.57 9.322	Li										2	Be																							
22.989768 97.72 883 0.97 0.93 5.139	24.3050 650 1090 1.74 1.09 7.646	11	12										18	Na	Mg																					
39.0983 69.38 759 0.82 4.341	40.078 154 1.54 1.00 6.113	19	20	21										22	23	24	25	26	27	28	29	30	31	32	33	34	35	36								
85.4678 39.31 688 1.532 0.82 4.177	87.62 177 1382 2.6 0.95 5.695	38	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
132.90543 28.44 871 1.879 0.79 3.894	137.327 727 1897 2.384 0.89 5.577	88	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
223.019727 677 3.894	(227.0278) -140 1007 0.7	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
	(Rn) ⁷² Francium	Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo																	

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140.115 799 3424 6.770 5.486 4.512	180.90765 931 3510 6.773 5.422	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
232.0381 1750 4788 11.72 1.3 6.08	232.0381 1572 4788 15.37 1.3 5.89	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
	(Rn) ⁷² Theoron	(Rn) ⁷² Protactinium	(Rn) ⁷² Uranium	(Rn) ⁷² Neptunium	(Rn) ⁷² Plutonium	(Rn) ⁷² Americium	(Rn) ⁷² Curium	(Rn) ⁷² Berkelium	(Rn) ⁷² Californium	(Rn) ⁷² Einsteinium	(Rn) ⁷² Fermium	(Rn) ⁷² Mendelevium	(Rn) ⁷² Nobelium	(Rn) ⁷² Lawrencium	

(A) Destructive Interference



(B) Standing Wave

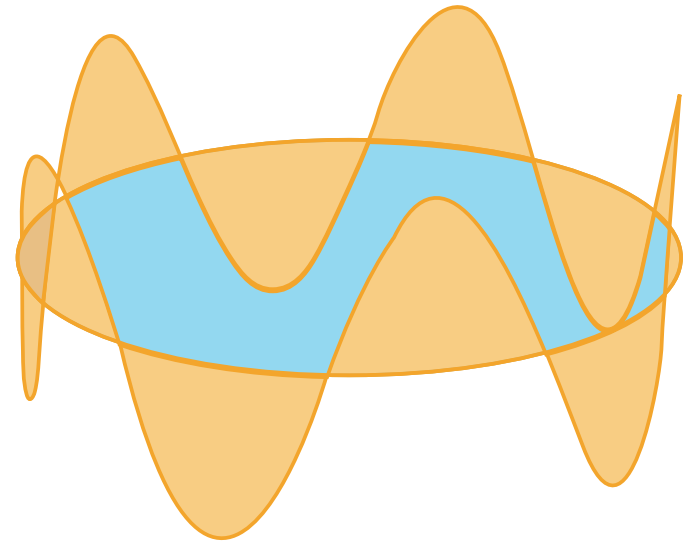
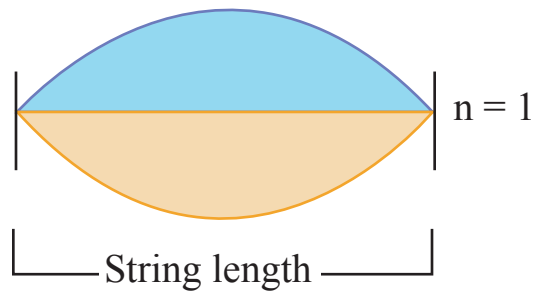
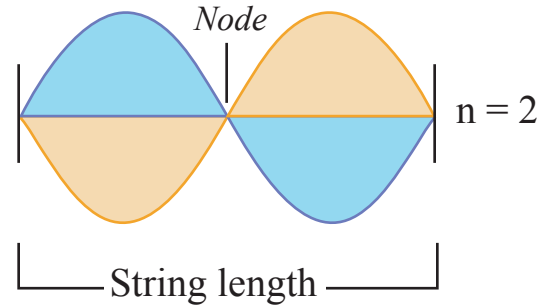


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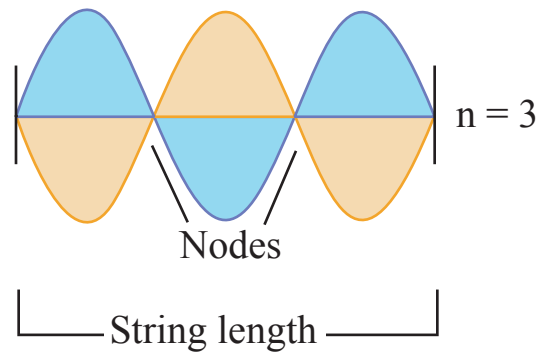
Fundamental



Overtone



Overtone



The Schrödinger Equation

$$-\frac{\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + V(x,t) \Psi(x,t) = i\hbar \frac{\partial \Psi(x,t)}{\partial t}$$

Wave Functions For One-Electron Atoms

$$\psi(1s) = \left(\frac{1}{\pi}\right)^{1/2} \left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0}$$

$$\psi(2s) = \frac{1}{4} \left(\frac{1}{2\pi}\right)^{1/2} \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) e^{-Zr/a_0}$$

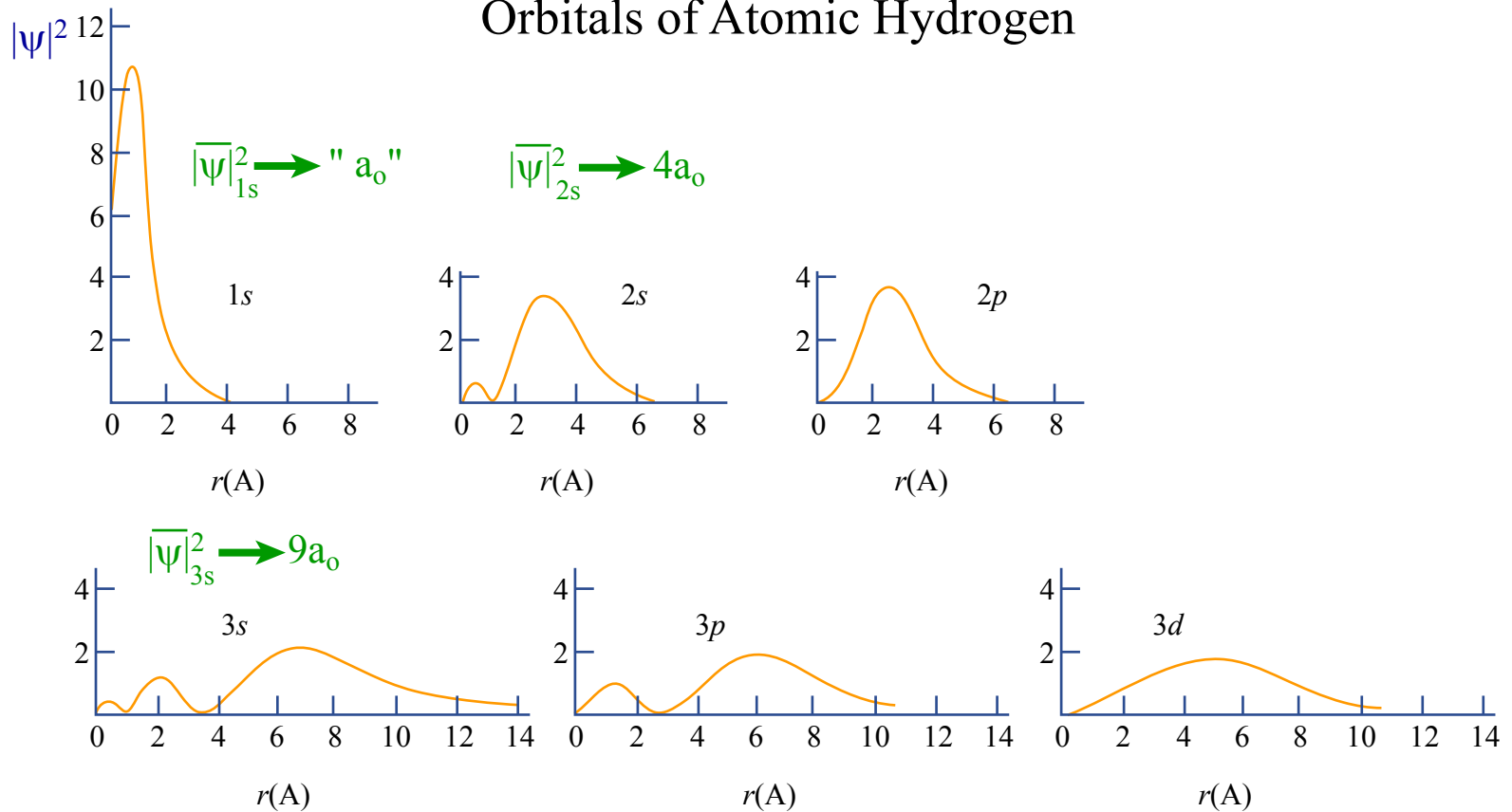
$$\psi(2p_x) = \frac{1}{4} \left(\frac{1}{2\pi}\right)^{1/2} \left(\frac{Z}{a_0}\right)^{3/2} \left(\frac{Zr}{a_0}\right) e^{-Zr/2a_0} \sin \theta \cos \phi$$

$$\psi(2p_y) = \frac{1}{4} \left(\frac{1}{2\pi}\right)^{1/2} \left(\frac{Z}{a_0}\right)^{3/2} \left(\frac{Zr}{a_0}\right) e^{-Zr/2a_0} \sin \theta \sin \phi$$

$$\psi(2p_z) = \frac{1}{4} \left(\frac{1}{2\pi}\right)^{1/2} \left(\frac{Z}{a_0}\right)^{3/2} \left(\frac{Zr}{a_0}\right) e^{-Zr/2a_0} \cos \theta$$

$$a_0 = \frac{h^2}{4\pi^2 m e^2} = 0.529 \times 10^{-8} \text{ cm}$$

Radial Probability Densities of Orbitals of Atomic Hydrogen



Radial Probability

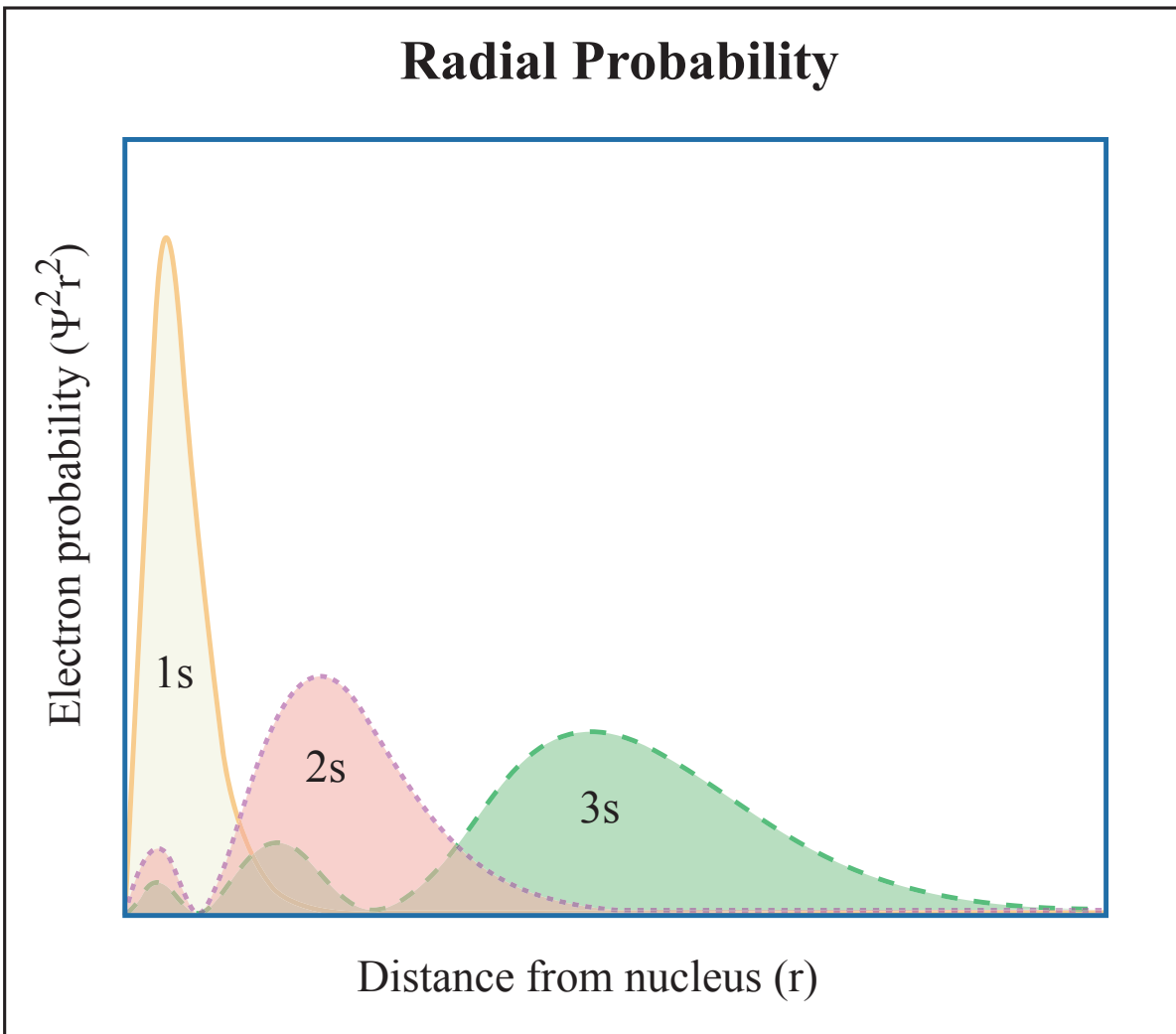


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Electron Probability

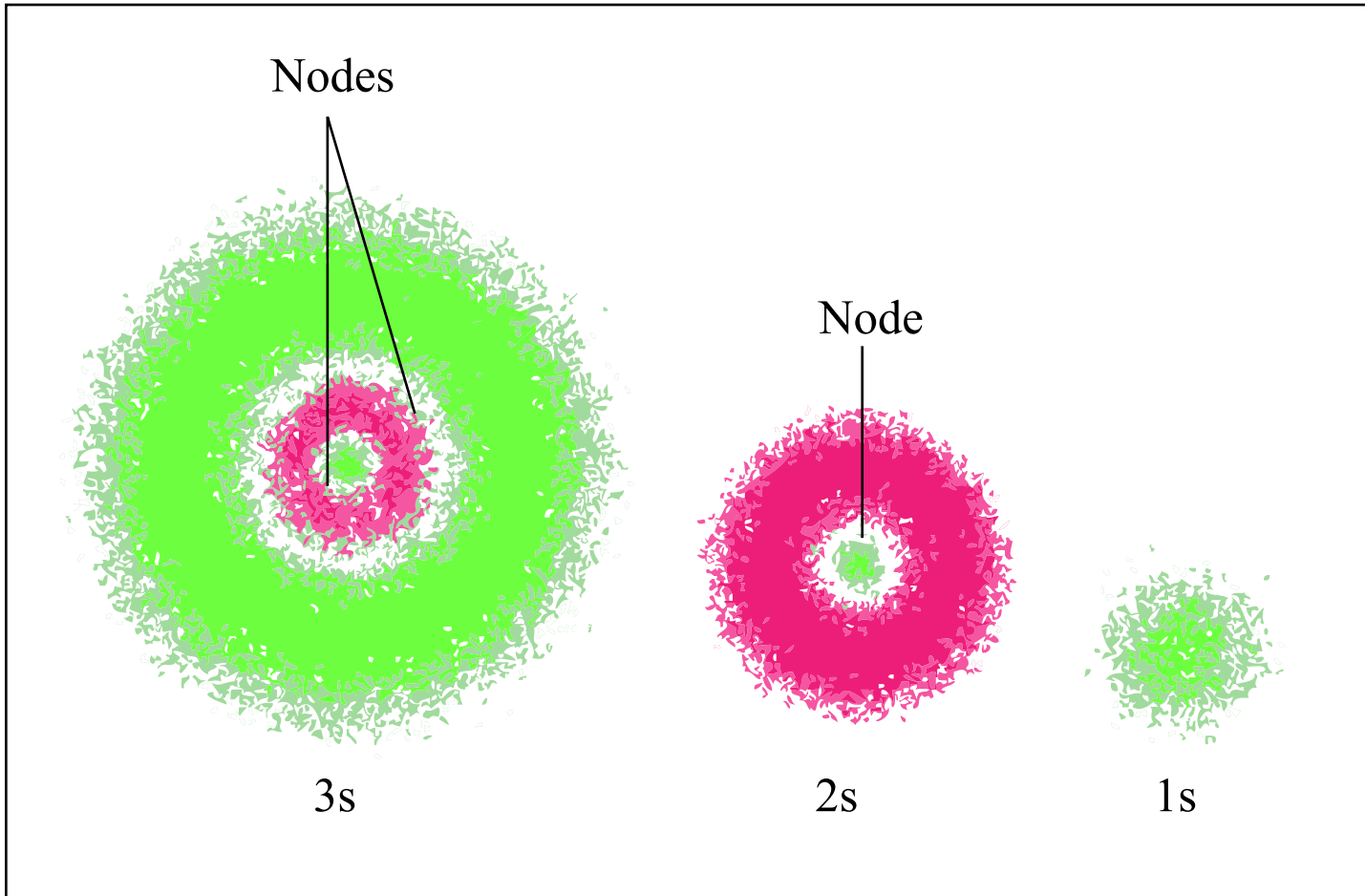
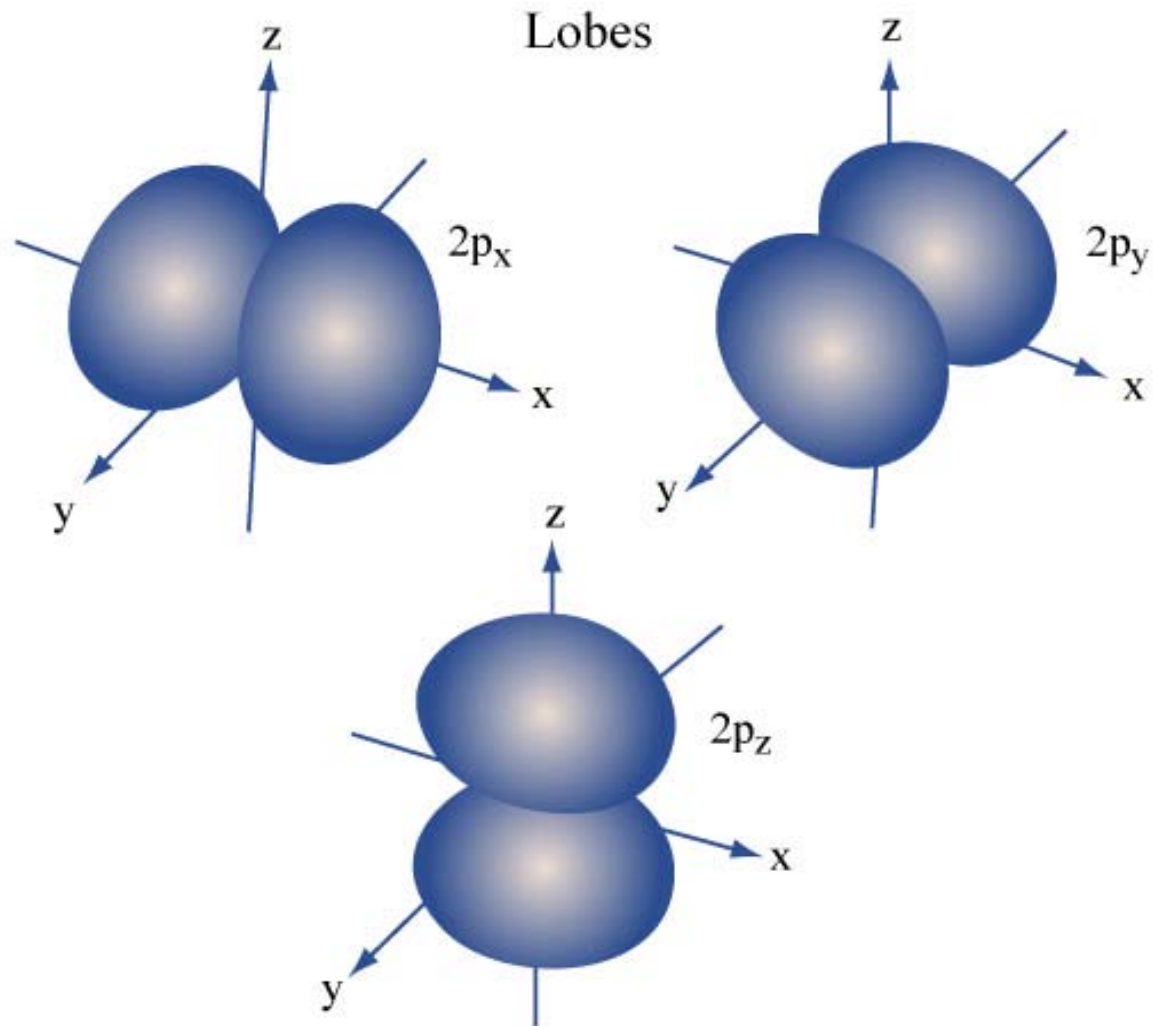


Image by MIT OpenCourseWare.



The 2-p Orbitals of Atomic Hydrogen

$$n = 2 ; l = 1 ; m = 1, 0, -1$$

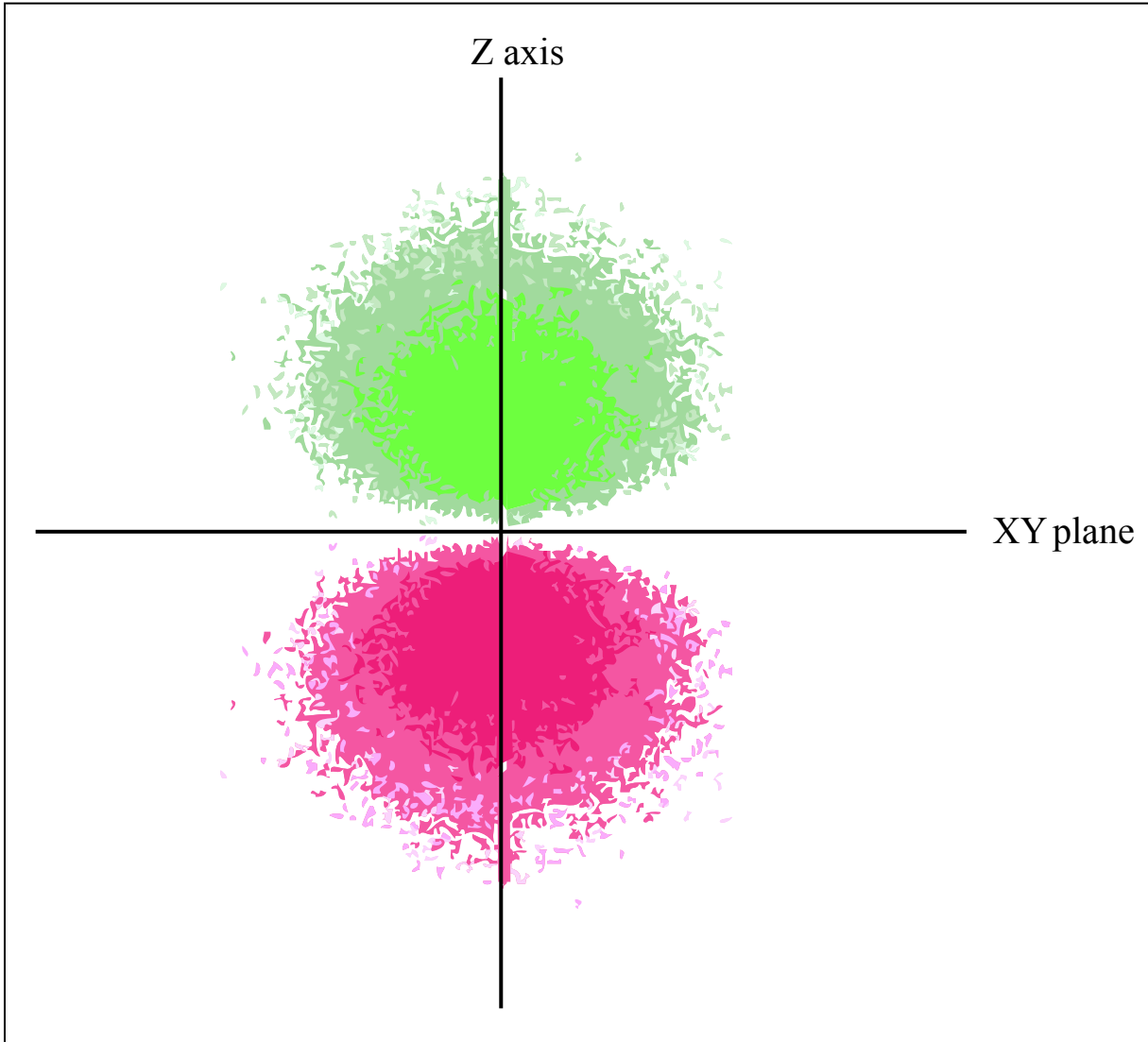


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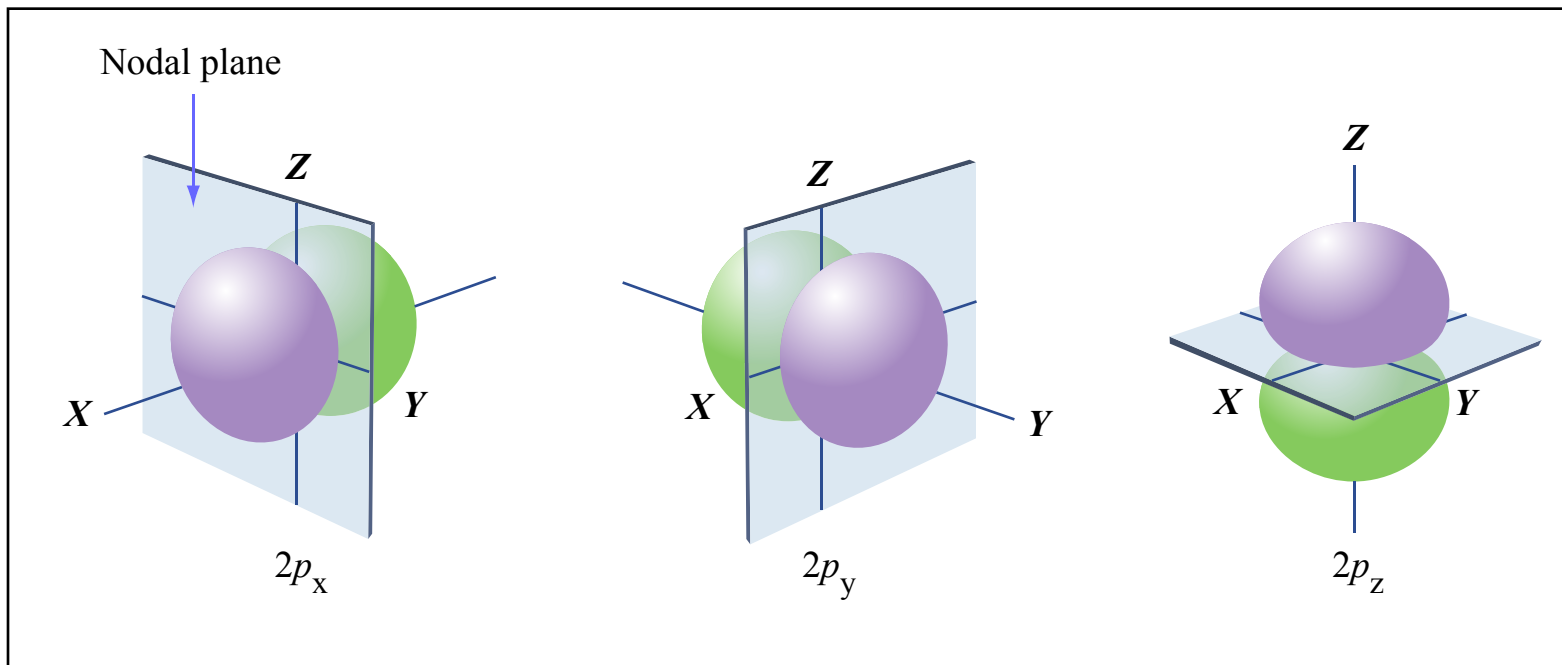
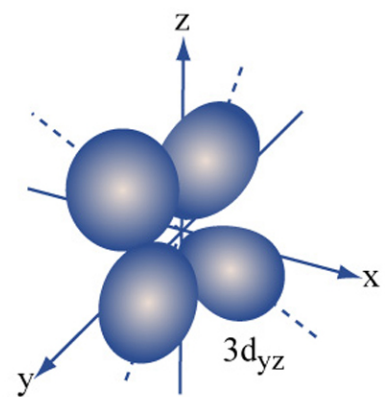
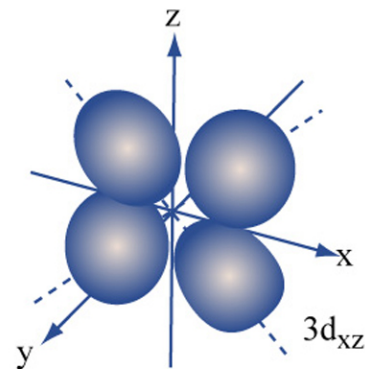
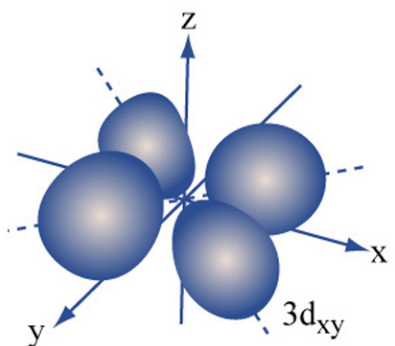
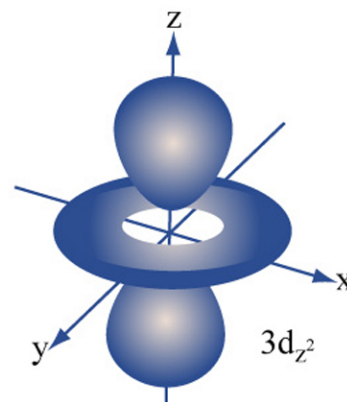
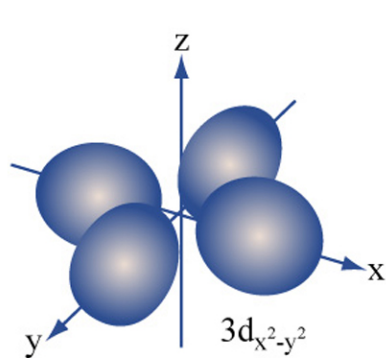


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The 3-D Orbitals of Atomic Hydrogen

$n=3; l=2; m=2, 1, 0, -1, -2$



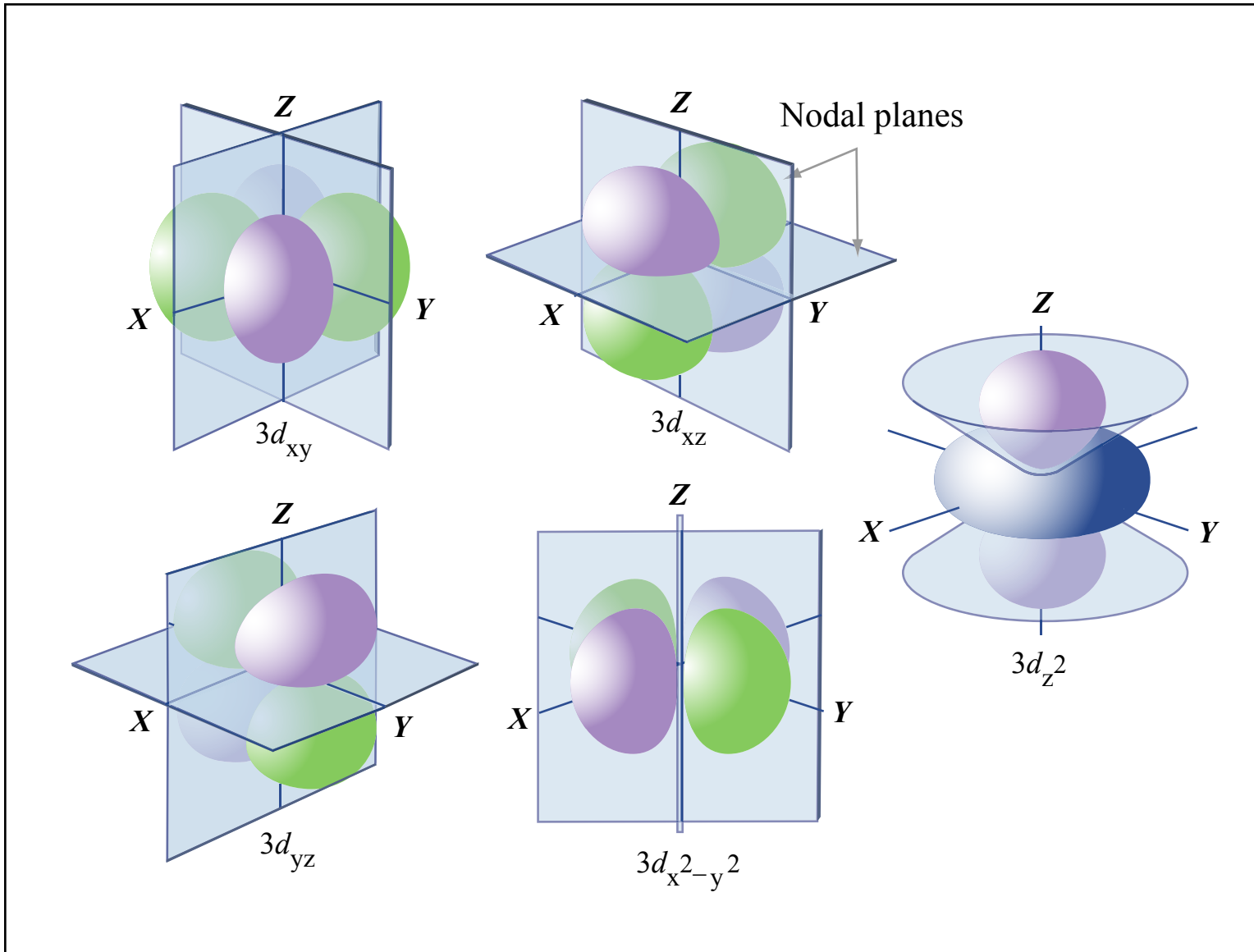


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Rigden, John S. *Hydrogen: The Essential Element*.

Cambridge, MA: Harvard University Press, 2003. ISBN: 9780674012523.

Peat, David F. *From Certainty to Uncertainty: The Story of Science and Ideas in the Twentieth Century*. Washington, DC: Joseph Henry Press, 2002. ISBN: 9780309076418.



Bohr, Heisenberg, Pauli (1934)

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3.091SC Introduction to Solid State Chemistry
Fall 2009

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