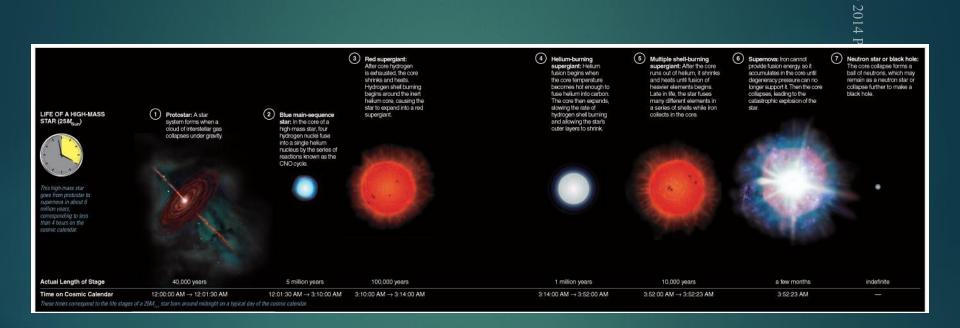
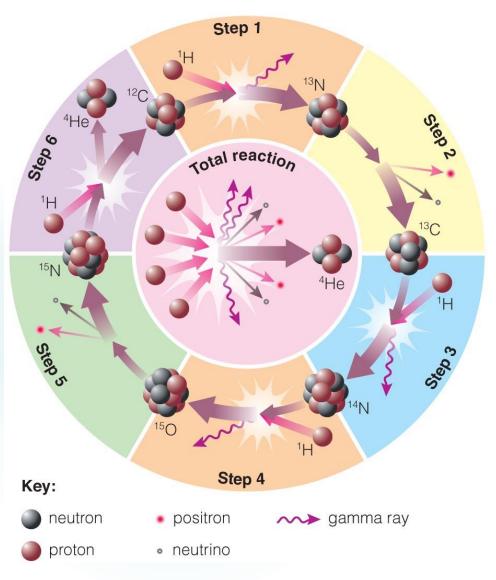
17.3 Life as a High-Mass Star

- Our goals for learning:
 - What are the life stages of a high-mass star?
 - How do high-mass stars make the elements necessary for life?
 - How does a high-mass star die?

What are the life stages of a highmass star?



CNO Cycle



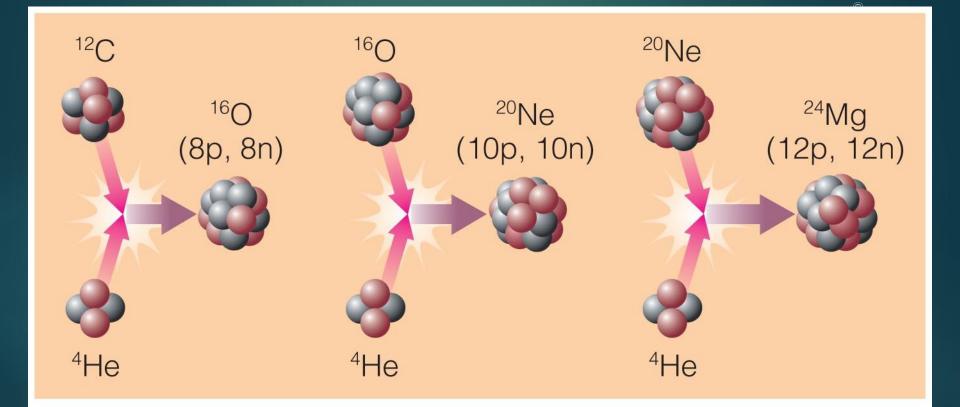
High-mass mainsequence stars fuse H to He at a higher rate using carbon, nitrogen, and oxygen as catalysts.

Greater core temperature enables hydrogen nuclei to overcome greater repulsion.

Life Stages of High-Mass Stars

- Late life stages of high-mass stars are similar to those of low-mass stars:
 - Hydrogen core fusion (main sequence)
 - Hydrogen shell burning (supergiant)
 - Helium core fusion (supergiant)

How do high-mass stars make the elements necessary for life?



a Helium-capture reactions.

				Key														
1 H Hydro 1.007	ogen			Magne	-	— Elem — Elem	iic numbe ent's syn ent's nan iic mass*	nbol ne							-			2 He Helium 4.003
3 Lithiu 6.94 11 Na Sodiu 22.99	i um 41 1 a um N	4 Beryllium 9.01218 12 Mgg Magnesium 24.305		*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.														10 Ne Neon 20.179 18 Ar Argon 39.948
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	32	33	34 Se	35 Br	36 Kr
Potass	sium	Calcium	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Ga Gallium	Ge Germanium	As Arsenic	Selenium	Bromine	Krypton
39.0		40.08 38	44.956 39	47.88	50.94 41	51.996 42	54.938 43	55.847 44	58.9332 45	58.69 46	63.546 47	65.39 48	69.72 49	72.59 50	74.922	78.96	79.904 53	83.80 54
R	1974 C	Sr	Y	Zr	Nb	Мо	Тс	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Те	Ĩ	Xe
Rubidi 85.4		Strontium 87.62	Yttrium 88.9059	Zirconium 91.224	Niobium 92.91	Molybdenum 95.94	Technetium (98)	Ruthenium 101.07	Rhodium 102.906	Palladium 106.42	Silver 107.868	Cadmium 112,41	Indium 114.82	Tin 118.71	Antimony 121.75	Tellurium 127.60	lodine 126.905	Xenon 131.29
55	88.	56		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cesiu	-	Barium		Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	lr Iridium	Pt Platinum	Au Gold	Hg Mercury	Ti Thallium	Pb Lead	Bi Bismuth	Polonium	At Astatine	Rn Radon
132.9	222	137.34		178.49	180.95	183.85	186.207	190.2	192.22	195.08	196.967	200.59	204.383	207.2	208.98	(209)	(210)	(222)
87	60 E	88		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fi	-	Ra Radium	- I	Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt	Darmotadtium	Rg	Cn Copernicium	Ununtrium	Uuq Ununguadium	Uup	Uuh	Uus	Uuo
(223	210/11	226.0254		(263)	(262)	(266)	(267)	(277)	(268)	(281)	(272)	(285)	(284)	(289)	(288)	(292)	(294)	(294)
				Lanthan	ide Ser	- ies	60	61	62	63	64	65	66	67	68	69	70	71
				La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				Lanthanum	Cerium	Praseodymium	100 B (100 C) (100 C)	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
				138.906	140.12	140.908	144.24	(145)	150.36	151.96	157.25	158.925	162.50	164.93	167.26	168.934	173.04	174.967
				Actinide	Series													
				89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
				Ac Actinium	Th Thorium	Pa Protactinium	U Uranium	Np Neptunium	Pu Plutonium	Am Americium	Cm Curium	Bk Berkelium	Cf Californium	Es Einsteinium	Fm Fermium	Md Mendelevium	No Nobelium	Lr Lawrencium
			-	227.028	232.038	231.036	238.029	237.048	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)

Big Bang made 75% H, 25% He; stars make everything else.

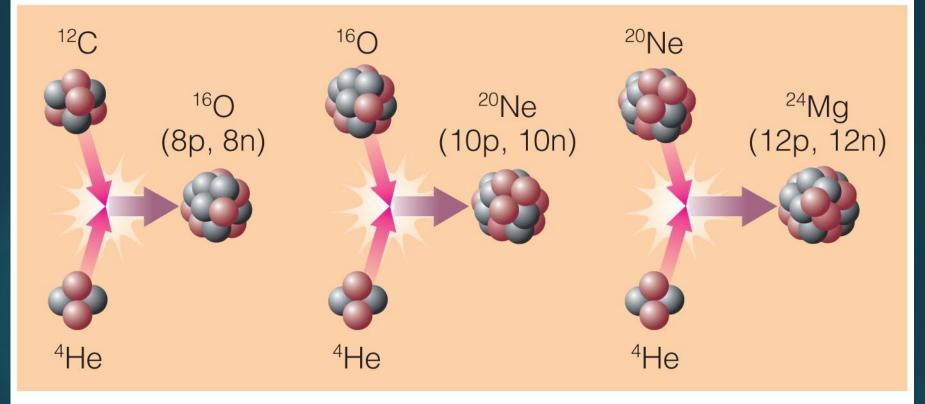
6.9419.01218weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.10.8112.01114.00715.999111213141516Na Sodium 22.990Mg 24.305Silicon 28.086Phosphorus 30.974Sulfur 32.0619 820 24.3052122 2223 2424 25 Cr26 Mn Fe 54.93827 28.08128 29 3031 31 32 3132 32 33 3434 32.0619 820 20 21.0221 22 22 22 2324 Cr Chromium 51.996Fe 54.938Co 55.847Ni 58.9332Cu 58.69Zn 63.54630 65.3931 32 33 3432 33 34 3434 32.0619 820 4.08821 4.95622 4.78823 50.9424 51.99625 54.93826 55.84727 58.933228 58.6929 63.54630 65.3931 69.7232 72.5933 74.92234 78.9637 838 39 4041 42 43 Nob Nobium Nolybdenum Technetium Technetium Ruthenium Ruthenium Ruthenium Ruthenium Rhodium Palladium Silver48 64 64748 4949 5050 51 52 5152 52 52 52	2 He Helium 4.003 9 10 Floorine Neon 18.988 20.179 17 18 CI Argon 35.453 39.948 35 36 Br Kr Bromine Krypton 79.904 83.80 53 54 I Xe
Li Lifhium 6.941Be beryllium 9.01218*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.B Boron 12.011C Nitrogen 12.011No Nitrogen 0.09,01218O Oxygen 14.00711 Na Sodium 22.99012 24.30522 2123 2424 2526 27 2827 28 28.02629 2930 31 3131 32 32.0631 32 33.334 32.0619 20 8 29.90820 21 20.80621 22 2223 24 2425 26 26 26 27 28 28.0629 29 30 30 31 31 32 31 32 3334 32 33 34 34 32.0619 8 40.0820 44.95621 47.8822 50.9425 54.71 54.93826 55.84729 58.933230 58.6931 63.54632 65.3933 69.72 72.5933 72.5934 74.92237 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	F Ne Fluorine Neon 18.988 20.179 17 18 Cl Ar Chlorine Argon 35.453 30.948 35 36 Br Kr 79.904 83.80 53 54
Sodium 22.990Magnesium 24.305Silicon 28.086Phosphorus 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 32.06Sulfur 30.974Sulfur 30.974Sulfur 30.974Sulfur 30.974Sulf	Chlorine Argon 35.453 39.948 35 36 Br Kr Bromine Krypton 79.904 83.80 53 54
K Potassium 39.098Ca Calcium 40.08Sc Scandium 44.956Ti Titanium 47.88V Vanadium 50.94Cr Chromium 51.996Mn Agas 54.938Fe Se Selenium 55.847Co Scoalt StopatNi Cu Cobalt 58.932Cu Science Selenium StoperCa Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Gallium Galli	Br Kr Bromine Krypton 79.904 83.80 53 54
39.098 40.08 44.956 47.88 50.94 51.996 54.938 55.847 58.932 58.69 63.546 65.39 69.72 72.59 74.922 78.96 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 Rb Sr Y Zr Nb Mo TC Ru Rh Pd Ag Cd In Sn Sb Te Rubidium Strontium Yttrium Zirconium Nobium Technetium Ruthenium Rhoium Falladium Silver Cadmium Indium Tin Antimony Tellurium	79.904 83.80 53 54
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te Rubidium Strontium Yttrium Zirconium Nobium Molybdenum Ruthenium Rhotium Palladium Silver Cadmium Indium Tin Antimony Tellurium	122702 C 1277
Rubidium Strontium Yttrium Zirconium Niobium Molybdenum Technetium Ruthenium Rhodium Palladium Silver Cadmium Indium Tin Antimony Tellurium	Xe
	lodine Xenon
	126.905 131.29
55 56 72 73 74 75 76 77 78 79 80 81 82 83 84 Cs Ba Hf Ta W Re Os Ir Pt Au Hg Ti Pb Bi Po	85 86 At Rn
	Astatine Radon
132.91 137.34 178.49 180.95 183.85 186.207 190.2 192.22 195.08 196.967 200.59 204.383 207.2 208.98 (209)	(210) (222)
87 88 104 105 106 107 108 109 110 111 112 113 114 115 116 Fr Ra Rf Db Sg Bh Hs Mt Ds Rg Cn Uut Uug Uup Uuh Uuh	117 118 Uus Uuo
Francium Radium Rutherfordium Dubnium Seaborgium Bohrium Hassium Meitnerium DarmstadtiumRoentgenium Copernicium Ununtrium UnunquadiumUnunpentium UnunhexiumUn	
(223) 226.0254 (263) (262) (266) (267) (277) (288) (281) (272) (285) (284) (289) (288) (292)	(294) (294)
Lanthanide Series	70 71
57 58 59 60 61 62 63 64 65 66 67 68 69 La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Tm	70 71 Yb Lu
Lanthanum Cerium Praseodymium Neodymium Promethium Samarium Europium Gadolinium Terbium Dysprosium Holmium Erbium Thulium Ytt	Ytterbium Lutetium
138.906 140.12 140.908 144.24 (145) 150.36 151.96 157.25 158.925 162.50 164.93 167.26 168.934 1	173.04 174.967
Actinide Series	
	102 103
	No Lr Nobelium Lawrencium
	Nobelium Lawrencium (259) (260)

▶ Helium fusion can make carbon in low-mass stars.

			Key														
1 H Hydrogen 1.00794			Magn	2 — g — esium 305 —	— Elem — Elem	iic numbe ent's syn ent's nan iic mass*	lod										2 He Helium 4.003
3 Li Lithium 6.941 11 Na	4 Be 9.01218 12 Mg		*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.														
Sodium 22.990 19	Magnesium 24.305 20	21	22	23 V	24	25	26	27	28	29	30	26.98 31	28.086 32	30.974 33	32.06 34	35.453 35	Argon 39.948 36
K Potassium 39.098	Ca Calcium 40.08	Scandium 44.956	Ti Titanium 47.88	Vanadium 50.94	Cr Chromium 51.996	Mn Manganese 54.938	Fe Iron 55.847	Co Cobalt 58.9332	Ni Nickel 58.69	Cu Copper 63.546	Zn Zinc 65.39	Ga Gallium 69.72	Ge Germanium 72.59	As Arsenic 74.922	Selenium 78.96	Br Bromine 79.904	Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.9059	40 Zr Zirconium 91.224	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 TC Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I lodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.34		72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os 0smium 190,2	77 Ir Iridium 192,22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Ti Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208,98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium	88 Ra Radium	-	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtiun	111 Rg Roentgenium	112 Cn Copernicium	113 Uut Ununtrium	114 Uuq Ununquadium	115 Uup Ununpentium	116 Uuh Ununhexium	117 Uus Ununseptiun	118 Uuo Ununoctium
(223)	226.0254		(263) Lanthan	(262) nide Ser	(266) ies	(267)	(277)	(268)	(281)	(272)	(285)	(284)	(289)	(288)	(292)	(294)	(294)
			57 La Lanthanum 138,906	58 Ce Cerium 140,12	59 Pr Praseodymium 140,908	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157,25	65 Tb Terbium 158,925	66 Dy Dysprosium 162.50	67 Ho Holmium 164,93	68 Er Erbium 167,26	69 Tm Thulium 168,934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
			Actinide			144.24	(140)	100.00	101.90	107.20	100.920	102.00	104.90	107.20	100.934	173.04	174.907
			89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	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 (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)

CNO cycle can change carbon into nitrogen and oxygen.

Helium Capture



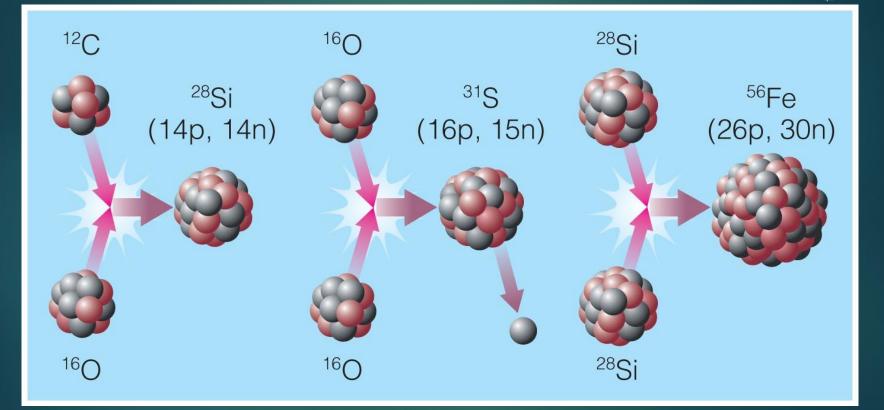
a Helium-capture reactions.

High core temperatures allow helium to fuse with heavier elements.

			Key														
1 H Hydrogen 1.00794		12 Atomic number Mg Element's symbol Magnesium Element's name 24.305 Atomic mass* 5 6 7 8 9															2 He Helium 4.003
3 Li Lithium 6.941 11 Na Sodium 22.990	4 Beryllium 9.01218 12 Mg Magnesium 24.305		*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.														
19	24.305	21	22	23	24	25	26	27	28	29	30	31	32	30.974	32.00	35.455	39.948 36
ĸ	Ca	Sc	Ti	v	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Potassium	Calcium	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Gallium	Germanium	Arsenic	Selenium	Bromine	Krypton
39.098	40.08	44.956	47.88	50.94	51.996	54.938	55.847	58.9332	58.69	63.546	65.39	69.72	72.59	74.922	78.96	79.904	83.80
37 Dh	38	39 Y	40 Zr	41 Nb	42	43 Tc	44	45	46	47	48	49	50	51 Sb	52	53	54
Rb Rubidium	Sr Strontium	Yttrium	Zirconium	Niobium	Mo Molybdenum		Ru Ruthenium	Rhodium	Pd Palladium	Ag	Cd Cadmium	Indium	Sn	Antimony	Tellurium	lodine	Xe Xenon
85.468	87.62	88.9059	91.224	92.91	95.94	(98)	101.07	102.906	106.42	107.868	112.41	114.82	118.71	121.75	127.60	126,905	131.29
55	56		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba		Hf	Та	W	Re	Os	Ir	Pt	Au	Hg	Ti	Pb	Bi	Po	At	Rn
Cesium	Barium		Hafnium	Tantalum	Tungsten	Rhenium	Osmium	Iridium	Platinum	Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon
132.91	137.34		178.49	180.95	183.85	186.207	190.2	192.22	195.08	196.967	200.59	204.383	207.2	208.98	(209)	(210)	(222)
87	88		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr Francium	Ra Radium	-	Rf Rutherfordium	Db Dubnium	Sg	Bh Bohrium	Hs Hassium	Mt	Ds	Rg	Cn Copernicium	Ununtrium	Uuq Ununguadium	Uup	Uuh	Uus	Uuo
(223)	226.0254		(263)	(262)	Seaborgium (266)	(267)	(277)	(268)	(281)	(272)	(285)	(284)	(289)	(288)	(292)	(294)	(294)
			Lanthan	nide Ser	'ies	60	61	62	63	64	65	66	67	68	69	70	71
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
			138.906	140.12	140.908	144.24	(145)	150.36	151.96	157.25	158.925	162.50	164.93	167.26	168.934	173.04	174.967
			Actinide	e Series	;												
			89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
		L	Actinium	Thorium	Protactinium	Uranium	Neptunium	Plutonium	Americium	Curium	Berkelium	Californium	Einsteinium	Fermium	Mendelevium	Nobelium	Lawrencium
			227.028	232.038	231.036	238.029	237.048	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)

Helium capture builds carbon into oxygen, neon, magnesium, and other elements.

Advanced Nuclear Burning

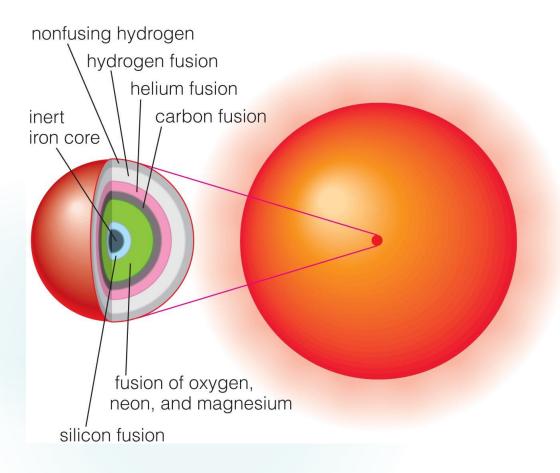


Core temperatures in stars with >8M_{Sun} allow fusion of elements as heavy as iron.

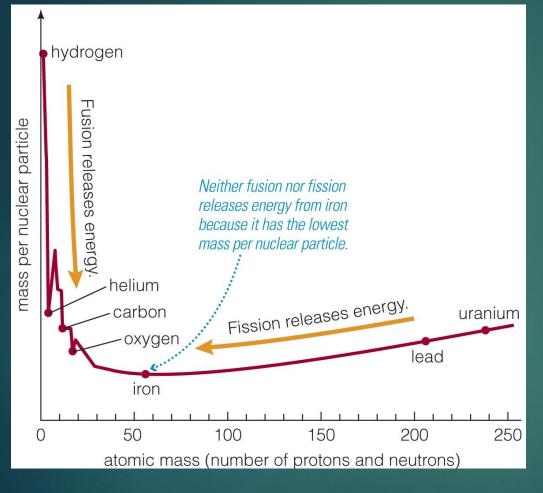
Г				Key														
	1 H Hydrogen 1.00794		12 Atomic number Mg Element's symbol Magnesium Element's name 24.305 Atomic mass* 5 6 7 8 9															2 He Helium 4.003
	3 Lithium 6.941 11 Na Sodium 22.990	4 Beryllium 9.01218 12 Mg Magnesium 24.305		*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth.														
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	39.948 36
	K Potassium	Ca Calcium	Scandiun	n Titanium	V Vanadium	Cr	Mn Manganese	Fe	Co	Ni Nickel	Cu Copper	Zn	Ga Gallium	Ge Germanium	As Arsenic	Selenium	Br Bromine	Kr Krypton
	39.098	40.08	44.956	47.88	50.94	51.996	54.938	55.847	58.9332	58.69	63.546	65.39	69.72	72.59	74.922	78.96	79.904	83.80
	37	38 Sr	39 Y	40 Zr	41 Nb	42	43	44	45	46	47	48	49	50	51 Sb	52	53	54
	Rb Rubidium	Strontium	Yttrium	Zirconium	Niobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium	In Indium	Sn Tin	Antimony	Te	lodine	Xe Xenon
	85.468	87.62	88.9059		92.91	95.94	(98)	101.07	102.906	106.42	107.868	112.41	114.82	118.71	121.75	127.60	126.905	131.29
	55	56		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
	Cs Cesium	Barium		Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	lr Iridium	Pt Platinum	Au Gold	Hg Mercury	Ti	Pb Lead	Bismuth	Polonium	At Astatine	Rn Radon
	132.91	137.34		178.49	180.95	183.85	186.207	190.2	192.22	195.08	196.967	200.59	204.383	207.2	208.98	(209)	(210)	(222)
	87	88		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
	Fr	Ra	-	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Uuq	Uup	Uuh	Uus	Uuo
	Francium (223)	Radium 226.0254		Rutherfordium (263)	Dubnium (262)	Seaborgium (266)	Bohrium (267)	Hassium (277)	Meitnerium (268)	(281)	(272)	Coperniciun (285)	Ununtrium (284)	(289)	(288)	n Ununhexium (292)	Ununseptiun (294)	(294)
				Lanthan				C1			C 4	05		07	<u> </u>		70	71
				57 La	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
				Lanthanum	Cerium I	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
				138.906	140.12	140.908	144.24	(145)	150.36	151.96	157.25	158.925	162.50	164.93	167.26	168.934	173.04	174.967
				Actinide	Series													
				89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
				Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
			L	Actinium 227.028	Thorium 232.038	Protactinium 231.036	Uranium 238.029	Neptunium 237.048	Plutonium (244)	Americium (243)	Curium (247)	Berkelium (247)	Californium (251)	Einsteinium (252)	Fermium (257)	Mendelevium (258)	Nobelium (259)	Lawrencium (260)
				221.020	202.000	201.000	200.023	201.040	(244)	(270)	(271)	(241)	(201)	(202)	(201)	(200)	(200)	(200)

Advanced reactions in stars make elements like Si, S, Ca, Fe.

Multiple Shell Burning

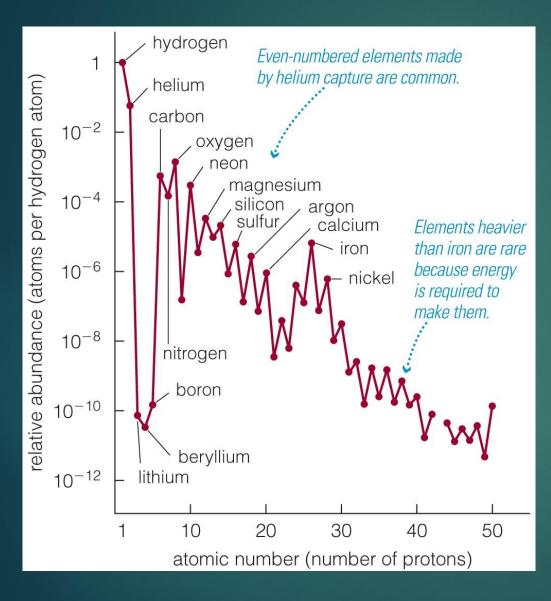


Advanced nuclear burning proceeds in a series of nested shells.



Iron is a dead end for fusion because nuclear reactions involving iron do not release energy.

 (This is because iron has lowest mass per nuclear particle.)

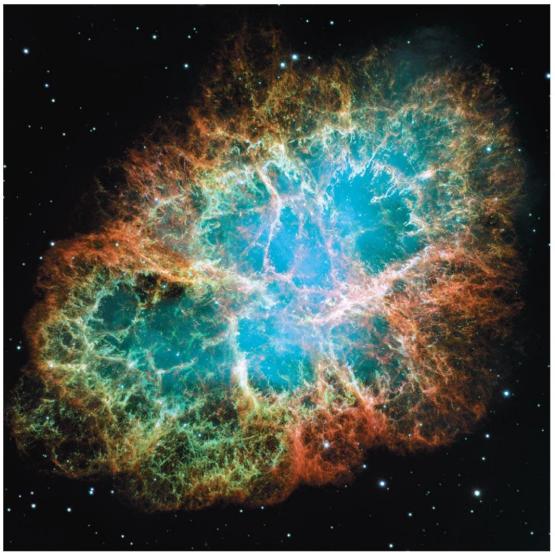


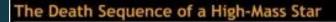
Evidence for helium capture:

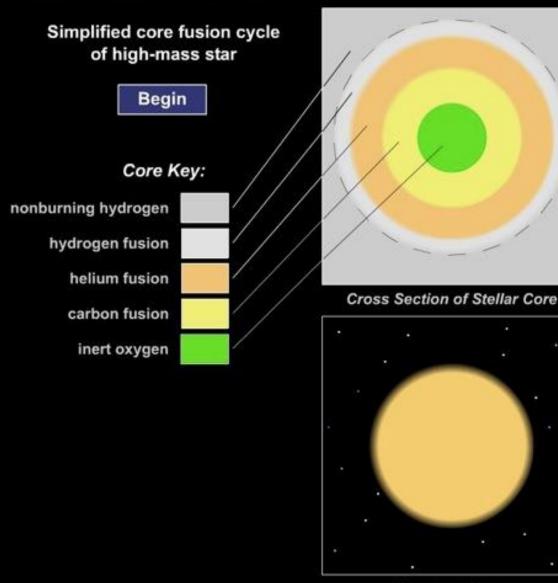
Pearson

Higher abundances of elements with even numbers of protons

How does a high-mass star die?





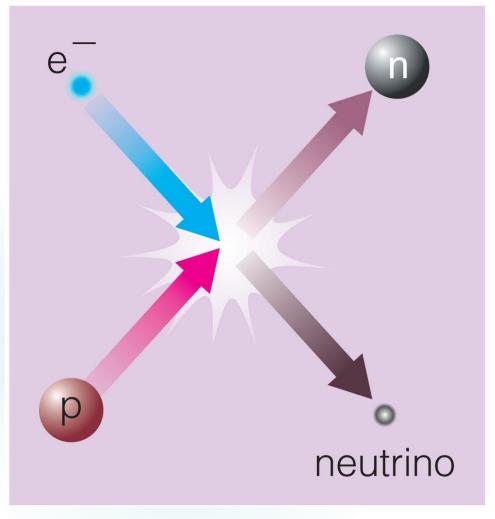


View from Space

Iron builds up in core until degeneracy pressure can no longer resist gravity.

The core then suddenly collapses, creating a supernova explosion.

Supernova Explosion



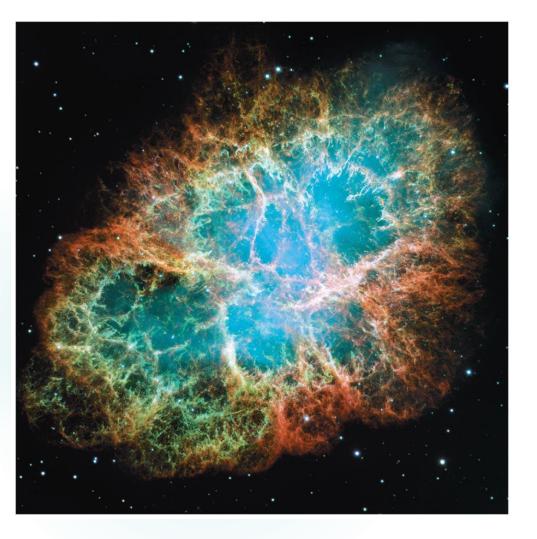
Core degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos.

Neutrons collapse to the center, forming a neutron star.

			Key														
1 H Hydrogen 1.00794		12 Atomic number Mg Element's symbol Magnesium Element's name 24.305 Atomic mass* 5 6 7 8 9															2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.01218	1	*Atomic masses are fractions because they represent a weighted average of atomic masses of different isotopes— in proportion to the abundance of each isotope on Earth. Beron 10.81 Beron 12.011 Beron														
Na Sodium 22.990	Mg Magnesium 24.305	AI SI P S CI Aluminum Silicon Phosphorus Sulfur Chlorine															Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.08	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.9332	28 Ni Nickel 58.69	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85,468	38 Sr Strontium 87.62	39 Y Yttrium 88.9059	40 Zr Zirconium 91,224	41 Nb Niobium 92,91	42 Mo Molybdenum 95,94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106,42	47 Ag Silver 107.868	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118,71	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 Iodine 126,905	54 Xe Xenon 131.29
55 Cs Cesium	56 Ba Barium	00.3033	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Ti Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
132.91 87 Fr Francium	137.34 88 Ra Radium		178.49 104 Rf Rutherfordium	180.95 105 Db Dubnium	183.85 106 Sg Seaborgium	186.207 107 Bh Bohrium	190.2 108 Hs Hassium	192.22 109 Mt Meitnerium	195.08 110 Ds Darmstadtiur	196.967 111 Rg Roentgenium	200.59 112 Cn Copernicium	204.383 113 Uut Ununtrium	207.2 114 Uuq Ununguadium	208.98 115 Uup Ununpentiun	(209) 116 Uuh Ununhexium	(210) 117 Uus Ununseptium	(222) 118 Uuo Ununoctium
(223)	226.0254	50	(263)	(262)	(266)	(267)	(277)	(268)	(281)	(272)	(285)	(284)	(289)	(288)	(292)	(294)	(294)
			57 La Lanthanum 138.906	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144,24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158,925	66 Dy Dysprosium 162,50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
			Actinide			11121	(140)	100.00	101.00	101.20	.00.020	102.00	101.00	101.20	.00.004	.10.01	
			89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	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 (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)

Energy and neutrons released in supernova explosion enable elements heavier than iron to form, including gold and uranium. 2014 Pearson Education, Ind

Supernova Remnant



Energy released by the collapse of the core drives the star's outer layers into space.

The Crab Nebula is the remnant of the supernova seen in A.D. 1054.

Supernova 1987A



The closest supernova in the last four centuries was seen in 1987.

Rings around Supernova 1987A



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The supernova's flash of light caused rings of gas around the supernova to glow.

Impact of Debris with Rings



More recent observations show the inner ring lighting up as debris crashes into it.

What have we learned?

What are the life stages of a high-mass star?

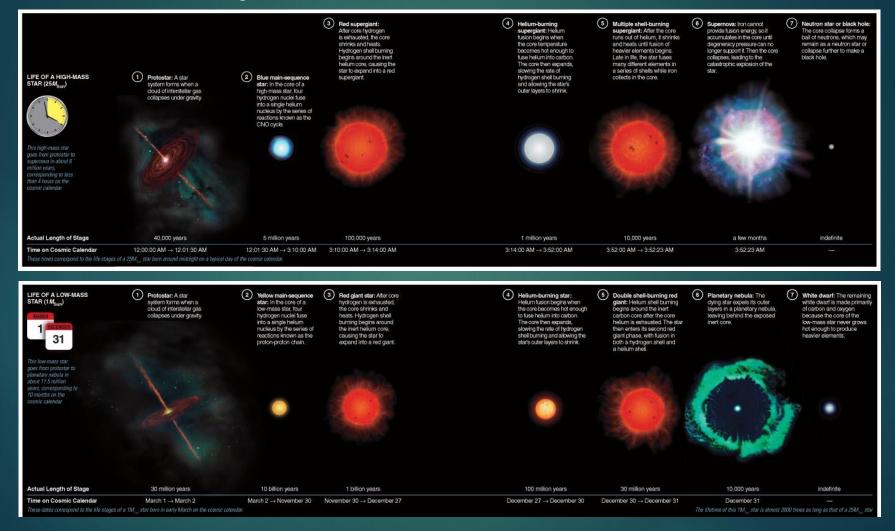
- They are similar to the life stages of a low-mass star.
- How do high-mass stars make the elements necessary for life?
 - Higher masses produce higher core temperatures that enable fusion of heavier elements.
- How does a high-mass star die?
 - Its iron core collapses, leading to a supernova.

17.4 The Roles of Mass and Mass Exchange

Our goals for learning:

- How does a star's mass determine its life story?
- How are the lives of stars with close companions different?

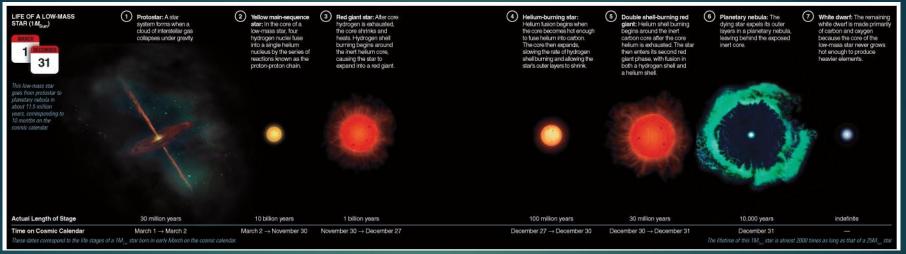
How does a star's mass determine its life story?



Role of Mass

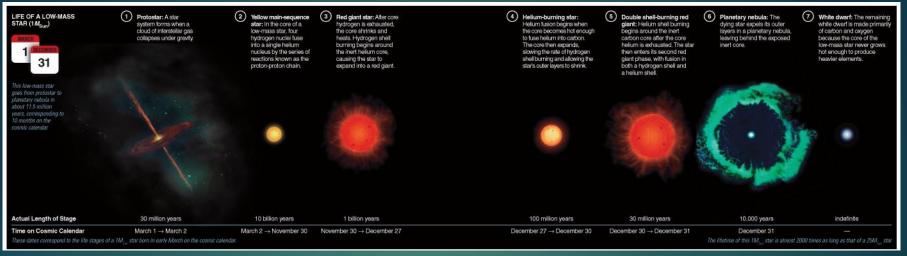
- A star's mass determines its entire life story because it determines its core temperature.
- High-mass stars with > 8M_{Sun} have short lives, eventually becoming hot enough to make iron, and end in supernova explosions.
- Low-mass stars with < 2M_{Sun} have long lives, never become hot enough to fuse carbon nuclei, and end as white dwarfs.
- Intermediate-mass stars can make elements heavier than carbon but end as white dwarfs.

Low-Mass Star Summary



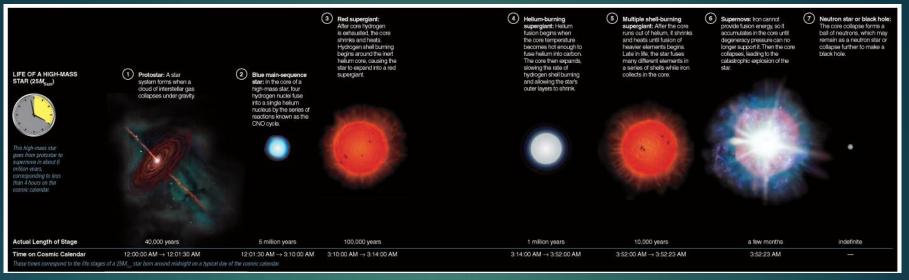
- 1. Main sequence: H fuses to He in core.
- 2. Red giant: H fuses to He in shell around He core.
- 3. Helium core burning: He fuses to C in core while H fuses to He in shell.
- 4. Double shell burning: H and He both fuse in shells.
- 5. Planetary nebula leaves white dwarf behind.

Reasons for Life Stages



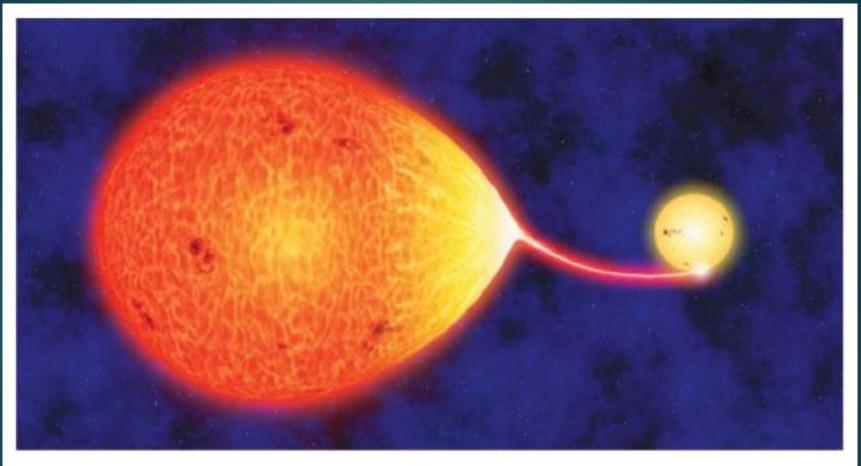
- Core shrinks and heats until it's hot enough for fusion.
- Nuclei with larger charge require higher temperature for fusion.
- Core thermostat is broken while core is not hot enough for fusion (shell burning).
- Core fusion can't happen if degeneracy pressure keeps core from shrinking.

Life Stages of High-Mass



- 1. Main sequence: H fuses to He in core.
- 2. Red supergiant: H fuses to He in shell around He core.
- 3. Helium core burning:
- 4. He fuses to C in core while H fuses to He in shell.
- 5. Multiple shell burning:
- 6. Many elements fuse in shells.
- 7. Supernova leaves neutron star behind.

How are the lives of stars with close companions different?



Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.

Thought Question

The binary star Algol consists of a 3.7M_{Sun} main-sequence star and a 0.8M_{Sun} subgiant star.

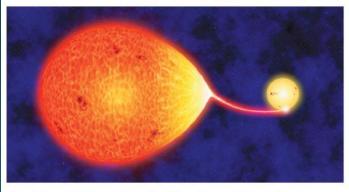
What's strange about this pairing?

How did it come about?

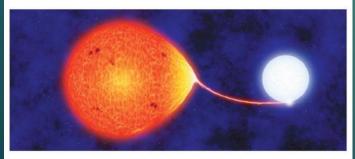
Thought Question Answers



Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



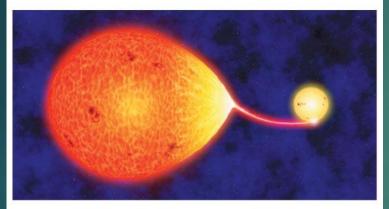
Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.



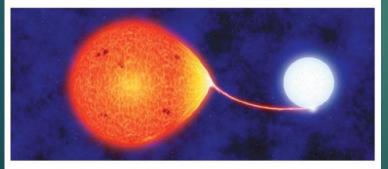
Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars. The stars in Algol are close enough that matter can flow from the subgiant onto the mainsequence star.



Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.



Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars.

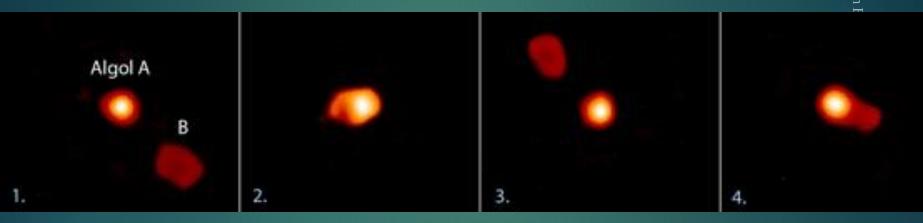
The star that is now a subgiant was originally more

As it reached the end of its life and As it reached the started to grow, it began to transfer mass to its companion (mass exchange).

Now the companion star is more massive.

Images of Algol

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What have we learned?

How does a star's mass determine its life story?

- Mass determines how high a star's core temperature can rise and therefore determines how quickly a star uses its fuel and what kinds of elements it can make.
- How are the lives of stars with close companions different?
 - Stars with close companions can exchange mass, altering the usual life stories of stars.