"Biogenic Elements" needed in large quantities to make living things

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
lydrogen																		helium
.1.																		2
н																		He
1,0079				Key:														4.0026
lithium 3	beryfium 4				tement name mic numi								boron 5	carbon 6	nitrogen 7	axygen 8	fluorine 9	neon 10
																	Ě	
ш	Be			S	/mb	OI .							В	С	N	0	-	Ne
6.941	9.0122			atomic weig	ht (mean rel	ative mass)							10.811	12.011	14,007	15.999	18,998	20.18
sodium 11	magnesium 12												aluminium 13	sticon 14	phosphorus 15	sufur 16	chlorine 17	argor
														Si	P	Š	ĊΙ	
Na	Mg												ΑI					Ar
22.990 otassium	24.305 carcium		scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	28.982 gellum	28.086 germanium	30.974 araenic	32.065 selenium	35.453 bromine	39.941 krypto
19	20		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kı
39,098	40,078		44,956	47,867	50,942	51,996	54,938	55,845	58,933	58,693	63,546	65,38	69,723	72,61	74,922	78,96	79,904	83,80
ubidium 37	strontium 38		yttrium	zirconium 40	niobium 41	molybdenum 42	technetium 43	ruthenium 44	rhodium 45	pattadium 46	silver 47	cadmium 48	indium 49	50	antimony 51	tellurium 52	iodine 53	xenor 54
			39 V														53	
Rb	Sr		Υ	Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	ln	Sn	Sb	Te		Χe
85,468	87.62		88,906	91,224	92,906	95,96	1961	101.07	102,91	105,42	107.87	112,41	114,82	118,71	121,76	127,60	126,90	131,21
55	barium 56	57-70	Tutetium 71	hafnium 72	tantalum 73	tungsten 74	menium 75	osmium 76	iridium 77	ptatinum 78	gold 79	mercury 80	thellium 81	ead 82	bismuth 83	potonium 84	astatine 85	rador 86
		*		Ĥf	Та	ŵ		2.7		Pt				Pb	Β̈́i			
Cs	Ba		Lu				Re	Os	lr		Au	Hg	TI			Ро	At	Rr
132,91	137,33		174,97	178,49 rutherfordium	180,95	183,84	186.21	190,23	192,22	195,08	196,97	200,59	204,38	207,2	208,98	[209] ununhexium	[210]	[222] ununocti
rancium 87	radium 88	89-102	103	104	dubnium 105	seaborgium 106	107	hassium 108	meitnerium 109	darmstadtium 110	roentgenium 111	ununblum 112	ununtrium 113	ununquadium 114	ununpentium 115	116	ununseptium 117	118
۴̈́г	Řа	**	Lr	Rf	Db		Bh	Hs	Мt	Ds		Uub			Uup			Uu
						Sg												
[223]	[226]		[262]	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]		[294]

*lanthanoids

**actinoids

	anthanum				promethium	samarium	europium	gadolinium	terbium	dysprosium	holmium	erbium	tholum	ytterbium
	57	58	59	60	61	62	63	64	65	66	67	68	69	70
ls	1 2	Ce	Dr	Nd	Pm	Sm	Eu	Gd	Tb	Dv	Но	Fr	Tm	Yb
15	La	Ce	FI.	Nu	F111	3111	⊏u	Gu	ID	DУ	по			ID
	138.91	140.12	140.91	144.24	[145]	150.38	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.06
	actinium	thorium	protectinium	uranium	neptunium	protonium	americium	curium	berkelium	californium	einsteinium		mendelevium	nobelium
	89	90	91	92	93	94	95	96	97	98	99	100	101	102
	Ac	Th	Pa	- 11	Nρ	Pu	Λ	Cm	Bk	Cf	Fe	Em	Md	No
	AC	111	ra	U	ир	ru	AIII	CIII	DK	CI	ES	Fm	IVIC	INO



"Biogenic Elements" needed in large quantities to make living things

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen 1																		helium 2
н																		He
1,0079 lithium	beryflium	ì		Key:	element name		ì					1	boron	carbon	nitrogen	axygen	fluorine	4.0026 neon
3	4			ate	omic numi	ber							5	6	7	8	9	10
Li	Be			S	ymb	ol							В	С	N	0	F	Ne
6.941	9.0122				ight (mean rel								10.811	12.011	14.007	15.999	18,998	20.180
sodium 11	magnesium 12												aluminium 13	sticon 14	phosphorus 15	sufur 16	chlorine 17	argon 18
Na	Mg												Αl	Si	P	S	CI	Ar
22.990	24,305												26,982	28,086	30,974	32,065	35,453	39,948
potassium 19	calcium 20		scandium 21	titanium 22	vanadium 23	chromium 24	manganese 25	iron 26	cobalt 27	nickel 28	copper 29	zinc 30	gellum 31	germanium 32	arsenic 33	selenium 34	bromine 35	krypton 36
K	Са		Sc	Τi	v	Ć۲	Mn	Ге		Ν̈́i	Ću	Ζ̈́n	Ğa	Ğe		Se	Β̈́r	Κ̈́r
									Со						As			
39,098 rubidium	40,078 strontium		44,958 vttrium	47,867 zirconium	50,942 niobium	51,996 molybdenum	54,938 technetium	55,845 ruthenium	58,933 rhodium	58,693 patadium	63,546 silver	65,38 cadmium	69,723 indium	72,61 tin	74,922 antimony	78.96 tetlurium	79,904 iodine	83,80 xenon
37	38		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr		Υ	Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	ln	Sn	Sb	Te		Xe
85,468	87,62		88,906	91,224	92,906	95,96	[96]	101.07	102,91	105,42	107.87	112,41	114,82	118,71	121,76	127,60	126,90	131,29
caesium 55	56	57-70	Tutetium 71	hafnium 72	tantalum 73	tungsten 74	rhenium 75	osmium 76	ridium 77	ptatinum 78	gold 79	mercury 80	thellium 81	Bad 82	bismuth 83	potonium 84	astatine 85	radon 86
Cs	Ba	*	Lu	Hf	Ta	w	Re	Os	ĺr	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132,91	137,33		174,97	178,49	180,95	183,84	186,21	190,23	192,22	195,08	196,97	200,59	204,38	207.2	208,98	[209]	12101	[222]
francium	radium		lawrendum	rutherfordium	dubnium	seaborgium	bohrium	hassium	meltnerium	darmstadtium	roentgenium	ununblum	ununtrium	ununquadium	ununpentium	ununhexium	ununseptium	ununoctium
87	88	89-102 **	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds		Uub			Uup		uus	Uuo
[223]	[226]		[262]	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]	_	[294]
			tanthanum 57	cerium 58	praseodymiun 59	neodymium 60	promethium 61	samarium 62	europium 63	gadofnium 64	terbium 65	dysprosium 66	holmium 67	erblum 68	thulum 69	ytterbium 70		
	*lantha	moido	l a	Co	Dr	NA	Dm	Sm	En	Cd	Th	Dv	Нο	Er	Tm	Vh		

*lanthanoid

**actinoids

138.91 140.12	140.91 14 protactinium ura	144.24 [145] ranium neptunium 92 93 U Np	150.38 plutonium 94	151.96 americium 95	157.25 curium 96 Cm	158.93 berkelum 97	162.50 calfornium 98 Cf	164.93 einsteinium 99	167.26	168.93 mendelevium 101	173.06 nobelum 102 No
138.91 140.12			150.38		157.25	158.93	162.50		167.26	168.93	173.06
us La Oe		144	OIII	Lu	Ju	10	Dy	110			ID
ds La Ce	Pr N	Nd Pm	Sm	Eu	Gd	Tb	Dv	Но	Er	Tm	Yb
57 58		60 promethium	samarium 62	europium 63	gadolnium 64	terbium 65	dysprosium 66	holmium 67	erbium 68	thulum 69	ytterbium 70

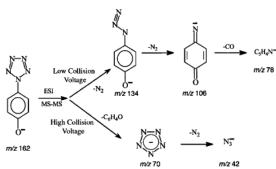


1 hydrogen	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18 helum 2
H 1,0079				Key:														He 4,0026
lithium 3	beryfium 4				dement name omic numb								boron 5	carbon 6		axygen 8	fluorine 9	neon 10
Ľi	Be												B	Č		Ô	Ě	Ne
					ymb								_			_		
6.941 sodium	9.0122 magnesium			atomic wei	ght (mean rela	ative mass)	J						10.811 aluminium	12,011 slicon	14,007 phosphorus	15.999 su l ur	18,998 chlorine	20.180 argon
11	12												13	14	15	16	17	18
Na	Mg												Al	Si	P	S	CI	Ar
22.990	24.305												26.962	28.086	30.974	32.065	35.453	39.948
potassium 19	calcium 20		scandium 21	titanium 22	vanadium 23	chromium 24	manganese 25	iron 26	cobst 27	nickel 28	copper 29	zinc 30	gellum 31	germanium 32	arsenic 33	selenium 34	bromine 35	krypton 36
				Τ̈́i	ν̈́													
K	Ca		Sc		•	Cr	Mn	Fe	Со	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39,098 rubidium	40,078 strontium		44,956 vttrium	47,867 zirconium	50,942 niobium	51,996 molybdenum	54,938 technetium	55,845 ruthenium	58,933 rhodium	58,693 patadium	63,546 silver	65,38 cadmium	69,723 indium	72,61 tin	74,922 antimony	78.96 tellurium	79,984 iodine	83,80 xenon
37	38		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr		Υ	Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	ln	Sn	Sb	Te		Xe
85,468	87.62		88,906	91,224	92,906	95,96	1981	101,07	102,91	106,42	107.87	112,41	114,82	118,71	121,76	127,60	126,90	131,29
caesium 55	barium 56	57-70	Tutetium 71	hafnium 72	tantalum 73	tungsten 74	rhenium 75	osmium 76	iridium 77	ptatinum 78	gold 79	mercury 80	thellum 81	ead 82	bismuth 83	potonium 84	astatine 85	radon 86
Cs	Ва	*	Lu	Hf	Ta	W	Re	Os	lr	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132,91	137,33		174,97	178,49	180,95	183,84	186,21	190,23	192,22	195,08	196,97	200,59	204,38	207.2	208,98	[209]	[210]	[222]
francium	radium		lawrendum	rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentgenium	ununblum	ununtrium	ununquadium	ununpentium	ununhexium	ununseptium	ununoctium
87	88	89-102 **	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
[223]	[226]		[262]	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]		[294]
			lanthanum	cerium	presendymium	neodymium	I promethium	samarium		I gadolinium	l terbium		holmium	l erbium	I tholium	vtterbium	1	
			57	58	59	60	61	62	europium 63	64	65	dysprosium 66	67	68	69	70		
	*lantha	noids	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb		
			138.91 actinium	140.12	140.91	144.24	[145]	150.36 plutonium	151.96	157.25	158.93	162.50	164.93	167.26 fermium	168.93 mendelevium	173.06 nobelium		
			actinium 89	thorium 90	protectinium 91	uranium 92	neptunium 93	94	americium 95	ourium 96	berketum 97	californium 98	einsteinium 99	100	mendelevium 101	102		
	**actin	oids	Ac	Th	Pa	Ü	Nр	Pu	Am		Bk	Cf	Es	Fm	Md	No		
					-	_		-	1		1			1			ı	

1 hydrogen 1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18 helium 2
1,0079 Rhium	bery¶ium				element name		1					ı	boron	carbon	nitrogen	axygen	fluorine	He 4,0026 neon
3 Li	80122			S	ymbo	ol							5 B 10.811	C 12.011		8	9 F 18,998	Ne 20,180
sodium 11 Na	magnesium 12 Mg			atomic we	дт упын гы	azve mass)	J						atuminium 13	slicon 14 Si	phosphorus 15	sufur 16 S	chlorine 17	argon 18 Ar
22.990 potassium 19	24.305 calcium 20		scandium 21	titanium 22	vanadium 23	chromium 24	manganese 25	iron 26	cobalt 27	nickel 28	copper 29	zinc 30	26.982 gallum 31	28.086 germanium 32	30,974 arsenic 33	32.065 selenium 34	35.453 bromine 35	39.948 krypton 36
K 39.098	Ca		Sc 44,956	Ti 47,867	V 50,942	Cr 51,996	Mn 54,938	Fe 55,845	Co	Ni 58,693	Cu 63,546	Zn	Ga 69,723	Ge	As 74,922	Se	Br 79,904	Kr 83,80
Rb	strontium 38 Sr		yttrium 39	zirconium 40 Zr	Nb	Mo	43 TC	Ru	rhodium 45 Rh	Pd Pd	47 A CI	Cd Cd	49	Sn	sntimony 51 Sb	Te	iodine 53	Xenon 54 Xe
85,468	87,62		88,906	91,224	92,906	95,96	1981	101,07	102.91	106,42	Ag	112,41	114,82	118,71	121,76	127,60	126,90	131,29
caesium 55	56	57-70	71	hafnium 72	tantalum 73	tungsten 74	rhenium 75	osmium 76	iridium 77	ptatinum 78	gold 79	mercury 80	thellum 81	82	bismuth 83	potonium 84	astatine 85	radon 86
Cs	Ba	*	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132,91 francium 87	137,33 radium 88	89-102	174,97 lawrendium 103	178,49 rutherfordium 104	180,95 dubnium 105	183,84 seaborgium 106	186,21 bohrium 107	190,23 hassium 108	192,22 meitnerium 109	195,08 darmstadtium 110	196,97 roentgenium 111	200,59 ununblum 112	204,38 ununtrium 113	207,2 ununquadium 114	208,98 rununpentium 115	[209] ununhexium 116	[210] ununseptium 117	(222) ununoctium 118
Fr	Ra	**	Ľr	Rf	Db	Sg	Bh	Нs	Mt	Ds	Rg				Uup			Uuo
[223]	[226]		[262]	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]		[294]
			lanthanum	cerium	preseodymium	neodymium	promethium	samarium	europium	gadolinium	terbium	dysprosium	holmium	erbium	I thulum	vtterbium		
			57	58	59	60	61	62	63	64	65	66	67	68	69	70		
	*lantha	noids	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb		
			138.91 actinium	140.12 thorium	140.91 protectinium	144,24 uranium	[145] neptunium	150.36 plutonium	151.96 americium	157.25 curium	158.93 berkelium	162.50 californium	164.93 einsteinium	167.26 fermium	168.93 mendelevium	173.06 nobe l um		
			89	90	91	92	93	94	95	96	97	98	99	100	101	102		
	**actin	oids	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No		
			[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]	l	

1 hydroge	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18 helium
H																		He
1,0079 lithium	beryllium	1			element name		1						boron	carbon	nitrogen	axygen	fluorine	4.0026 neon
Li	Be				omic numi vmb								B	Ć		Ö	ř	Ne
6,941 sodium	9.0122				right (mean rela								10.811 aluminium	12,011 silicon	14,007	15,999 sufur	18,998 chlorine	20.180
11	magnesium 12												auminum 13	14	phosphorus 15	16	17	argon 18
Na													Αl	Si	Р	S	CI	Ar
22.990 potassiu	24.305 m calcium	4	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	28.982 gellum	28.086 germanium	30.974 arsenic	32.065 selenium	35.453 bromine	39.948 krypton
19	20		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39,098	40,078		44,956	47,867	50,942	51,996	54,938	55,845	58,933	58,693	63,546	65,38	69,723	72,61	74,922	78,96	79,904	83.80
rubidiur 37	strontium 38		yttrium 39	zirconium 40	niobium 41	motybdenum 42	technetium 43	ruthenium 44	rhodium 45	pattadium 46	sitver 47	cadmium 48	indium 49	50	antimony 51	tellurium 52	iodine 53	xenon 54
Rb			Ÿ	Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	ln	Sn	Sb	Te	Ï	Xe
85,465 caesiur	87.62 barium		88,906 Jutetium	91,224 hafnium	92,906 tantajum	95,96 tungsten	1981 rhenium	101,07 osmium	102,91 iridium	106.42 platinum	107.87 gold	112,41 mercury	114,82 thellium	118,71 lead	121,76 bismuth	127.60 polonium	126,90 astatine	131.29 radon
55	56	57-70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	*	Lu	Hf	Ta	w	Re	Os	l r	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132,91	137,33 1 radium		174,97	178,49	180,95 dubnium	183,84	186,21 bohrium	190,23	192,22 meitnerium	195,08	196,97 roentgenium	200,59 ununbium	204,38 ununtrium	207.2	208,98	[209]	[210]	[222]
franciur 87	1 radium 88	89-102	103	rutherfordium 104	105	seaborgium 106	107	hassium 108	109	darmstadtium 110	111	112	113	ununquadium 114	ununpentium 115	ununhexium 116	ununseptium 117	ununoctium 118
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Unit	Uuq	Uun	Uuh	Uus	Uuo
12231	[226]		12621	[267]	12681	12711	12721	12701	[276]	12811	[280]	12851	[284]	[289]	12881	[293]		[294]
			tanthanum 57	58	presectymium 59	neodymium 60	promethium 61	samarium 62	europium 63	gadolinium 64	terbium 65	dysprosium 66	holmium 67	erblum 68	thulum 69	ytterbium 70		
	*lanth:	anoids	La	Се	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb		
			138.91 actinium	140.12 thorium	140.91 protectinium	144,24 uranium	[145] neptunium	150.38 plutonium	151.96 americium	157.25 curium	158.93 berkelium	162.50 californium	164.93 einsteinium	167.26 fermium	168.93 mendelevium	173.06 nobelium		
			89	90	91	92	93	94	95	96	97	98	99	100	101	102		
	**actir	oids	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No		
			[227]	232.04	231.04	238.03	(237)	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	(259)		

1 hydrogen	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18 helium 2
H 1,0079				Key:														He 4,0026
lithium 3	beryflium 4				element name omic numl								boron 5	carbon 6		axygen 8	fluorine 9	neon 10
Li	Be			S	ymb	ol							В	C		0	F	Ne
6.941	9.0122				ight (mean rela								10.811	12,011		15,999	18,998	20.180
sodium 11	magnesium 12												aluminium 13	slicon 14	phosphorus 15	sufur 16	chlorine 17	argon 18
Na	Mg												Al	Si	P	S	CI	Ar
22,990 potassium	24.305 calcium		scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	28.982 gellum	28.086 germanium	30,974 arsenic	32.065 serenium	35.453 bromine	39.948 krypton
19	20		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
∣ K	Ca		Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39,098	40,078		44,956	47,867	50,942	51,996 molybdenum	54,938	55,845	58,933	58,693 pagadium	63,546	65,38 cadmium	69,723	72,61	74,922 antimony	78,96 tellurium	79,904	83,80
rubidium 37	strontium 38		yttrium 39	zirconium 40	niobium 41	42	technetium 43	ruthenium 44	rhodium 45	46	silver 47	48	indium 49	50	51	52	iodine 53	xenon 54
Rb	Sr		Υ	Zr	Nb	Мо	Tc	Ru	Rh	Pd	Ag	Cd	ln	Sn	Sb	Te		Xe
85,468 caesium	87,62 barium		88,906 Jutetium	91,224 hafnium	92,906 tantajum	95,96 tungsten	1981 thenium	101,07 osmium	102,91 iridium	106,42 platinum	107.87 gold	112,41 mercury	114,82 thallum	118,71 lead	121,76 bismuth	127.60 polonium	126,90 astatine	131,29 radon
55	56	57-70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	*	Lu	Hf	Ta	W	Re	Os	- Ir	Pt	Au	Hg	TI	Pb	Bi	Po	At	Rn
132,91 francium	137,33 radium		174,97 Jawrencium	178,49 rutherfordium	180,95 dubnium	183,84 seaborgium	186,21 bohrium	190,23 hassium	192,22 meitnerium	195,08 darmstadtium	196,97 roentgenium	200,59 ununblum	204,38 ununtrium	207,2 ununguadiun	208,98 ununpentium	[209] ununhexium	[210] ununseptium	[222] ununoctium
87	88	89-102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub			Uup		Uus	Uuo
[223]	[226]		[262]	[267]	[268]	[271]	[272]	[270]	[276]	[281]	[280]	[285]	[284]	[289]	[288]	[293]		[294]
			tanthanum 57	cerium 58	prasecdymium 59	neodymium 60	promethium 61	samarium 62	europium 63	gadolinium 64	terbium 65	dysprosium 66	holmium 67	erbium 68	tholum 69	ytterbium 70		
	*lantha	noide	Ľa	Сe	Pr	Nd	Pm	Sm	Eu	Gd	Τ̈́b	Ďу	Но	Ĕr	Tm	Υb		
	iarillia	irioids	138.91	140.12	140.91	144.24	[145]	150,36	151.96	157,25	158,93	162.50	164.93	167.26	168,93	173,06		
			actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium		
		oide																
	**actin	oide	Ac	Th	Pa	92 U	Np	Pu	Am	Cm	Bk	°8 Cf	Es	Fm	Md	No		



Scheme 1. ESI-MS-MS fragmentation of the mass-selected unlabeled 4-pentazolylphenolate anion at low and high collision voltages.

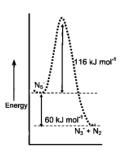


Figure 3. Activation energy barrier and decomposition enthalpy of the pentazolate anion calculated at the CCSD(T)/augcc-pVTZ level of theory.^[8]

Karl O. Christe et al., ACIE 1999, 38, 2004

$$\left[\underline{\underline{N}} - \underline{N} = \underline{N}\right]^{-} + \left[\underline{N} = \underline{N} - \underline{\underline{N}}\right]^{-} + \left[\underline{N} = \underline{N} - \underline{\underline{N}}\right]^{-}$$

Scheme 1. Resonance structures of N₃⁻ (1).

$$\begin{bmatrix} (-) & (+) & (-) \\ N = N = N \end{bmatrix}^{-} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (-) \\ N = N = N = N = N \end{bmatrix} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (+) & (-) \\ N = N = N = N = N = N \end{bmatrix}^{+}$$

$$1 \qquad 2 \qquad 3$$

Scheme 2. Addition of N^+ to N_3^- (1) to form N_4 (2) and N_5^+ (3) as well as the electronic charge distributions in 1–3.

$$\left[\left(\begin{array}{c} \left(\right) \right) \\ \left(\begin{array}{c} \left(\right) \right) \\ \end{array} \right) \\ \end{array} \right) \\ \end{array} \right) \end{array} \right) \right] \right) \right] \right]$$

Scheme 3. Resonance structures of N₅⁺ (3)

•

Karl O. Christe et al., ACIE 1999, 38, 2004

$$\left[\underline{\underline{N}} - \underline{N} = \underline{N}\right]^{-} \longrightarrow \left[\underline{N} = \underline{N} = \underline{N}\right]^{-} \longrightarrow \left[\underline{N} = \underline{N} - \underline{\underline{N}}\right]^{-}$$

Scheme 1. Resonance structures of N₃⁻ (1).

$$\begin{bmatrix} (-) & (+) & (-) \\ N = N = N \end{bmatrix}^{-} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (-) \\ N = N = N = N = N \end{bmatrix} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (+) & (-) \\ N = N = N = N = N = N \end{bmatrix}^{+}$$

$$1 \qquad 2 \qquad 3$$

Scheme 2. Addition of N^+ to N_3^- (1) to form N_4 (2) and N_5^+ (3) as well as the electronic charge distributions in 1–3.

Scheme 3. Resonance structures of N₅⁺ (3).

•

Karl O. Christe et al., ACIE 1999, 38, 2004

$$\left[\underline{\underline{N}} - \underline{N} = \underline{N}\right]^{-} \longrightarrow \left[\underline{N} = \underline{N} = \underline{N}\right]^{-} \longrightarrow \left[\underline{N} = \underline{N} - \underline{\underline{N}}\right]^{-}$$

Scheme 1. Resonance structures of N₃⁻ (1).

$$\begin{bmatrix} (-) & (+) & (-) \\ N = N = N \end{bmatrix}^{-} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (-) \\ N = N = N = N = N \end{bmatrix} \xrightarrow{+N^{+}} \begin{bmatrix} (-) & (+) & (+) & (+) & (-) \\ N = N = N = N = N = N \end{bmatrix}^{+}$$

$$1 \qquad 2 \qquad 3$$

Scheme 2. Addition of N+ to N3- (1) to form N4 (2) and N5+ (3) as well as the electronic charge distrubutions in 1-3.

$$\left[\left(\begin{array}{c} \left(\right) \right) \\ \left(\begin{array}{c} \left(\right) \right) \\ \end{array} \right) \\ \end{array} \right) \\ \end{array} \right) \end{array} \right) \right] \right) \right] \right]$$

Scheme 3. Resonance structures of N_c⁺ (3)

Nitrogen

The reaction of labeled HN_3 with $N_2F^+AsF_6^-$ produced a roughly equimolar mixture of N_5^+ with ^{15}N in either the 1- or 3-position [Eqs. (6), (7)].

$$N_{2}F^{*}AsF_{0}^{-} + H - \mathring{N} - N - N - N \longrightarrow \begin{bmatrix} N_{1} & N_{2} & N_{3} \\ N_{1} & N_{2} & N_{3} \end{bmatrix} \xrightarrow{N_{1}}^{*} AsF_{0}^{-} \quad (6)$$

$$N_{2}F^{*}AsF_{0}^{-} + H - N - N - \mathring{N} \longrightarrow \begin{bmatrix} N_{1} & N_{2} & N_{3} \\ N_{3} & N_{3} & N_{3} \\ N_{3} & N_{3} & N_{3} \end{bmatrix} \xrightarrow{N_{1}}^{*} AsF_{0}^{-} \quad (7)$$

The N_5 * As F_6 " salt is a white solid that is sparingly soluble in anhydrous HF. It is marginally stable at 22 °C and can be stored for weeks at -78°C without noticeable decomposition. It can be handled both in HF solution or as a solid and, in our experience, has not exploded during careful normal handling or when squashed with a stainless steel spatula at -196°C. It

N₂ is 78.1% of Earth's atmosphere by volume

- The number of moles of industrially produced NH₃ exceeds
- Proteins on average are about 15% nitrogen by weight
- In 1886 it was shown that N₂ can be "fixed" by certain
- Global N fixation, Haber:biological:atmospheric, 36:140:30 (in

- N₂ is 78.1% of Earth's atmosphere by volume
- The number of moles of industrially produced NH₃ exceeds that of any other commercial compound
- Proteins on average are about 15% nitrogen by weight
- \bullet In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- Global N fixation, Haber:biological:atmospheric, 36:140:30 (in 10^6 tons). The mass of Earth's atmosphere is approximately 5×10^9 million tons.

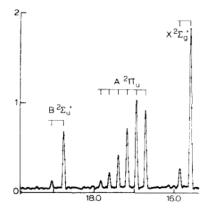
- N₂ is 78.1% of Earth's atmosphere by volume
- The number of moles of industrially produced NH₃ exceeds that of any other commercial compound
- Proteins on average are about 15% nitrogen by weight
- \bullet In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- Global N fixation, Haber:biological:atmospheric, 36:140:30 (in 10^6 tons). The mass of Earth's atmosphere is approximately 5×10^9 million tons.

- N₂ is 78.1% of Earth's atmosphere by volume
- The number of moles of industrially produced NH₃ exceeds that of any other commercial compound
- Proteins on average are about 15% nitrogen by weight
- ullet In 1886 it was shown that N_2 can be "fixed" by certain organisms in root nodules
- Global N fixation, Haber:biological:atmospheric, 36:140:30 (in 10^6 tons). The mass of Earth's atmosphere is approximately 5 \times 10^9 million tons.

- N₂ is 78.1% of Earth's atmosphere by volume
- The number of moles of industrially produced NH₃ exceeds that of any other commercial compound
- Proteins on average are about 15% nitrogen by weight
- ullet In 1886 it was shown that N_2 can be "fixed" by certain organisms in root nodules
- Global N fixation, Haber:biological:atmospheric, 36:140:30 (in 10^6 tons). The mass of Earth's atmosphere is approximately 5 \times 10^9 million tons.

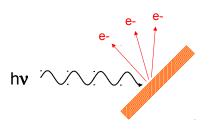
N₂ Photoelectron Spectrum (PES)

304 Å (40.8 eV) spectrum from J. Chem. Phys. 1975, vol. 62, 1447.



Photoelectric Effect

Ionization occurs when matter interacts with light of sufficient energy (Heinrich Hertz, 1886) (Einstein, A. Ann. Phys. Leipzig 1905, 17, 132-148.)







 E_{hn} = electron kinetic energy + electron binding energy

Photoelectron spectroscopy uses this phenomenon to learn about the electronic structure of matter

General Overview of Spectroscopy

- Spectroscopy uses interaction of electromagnetic radiation with matter to learn something about the matter.
- If electromagnetic radiation present is in resonance with the energy spacing between different states (electronic, vibrational, rotational, etc) of matter, radiation will be absorbed and transitions will occur.
- The radiation that is transmitted through the sample is measured, and spectrum can be reported as either transmittance or absorbance of radiation.
- · Photoelectron spectroscopy is entirely different!

Photoelectron vs Other Spectroscopies

Others

- Photon must be in resonance with transition energy
- Measure absorbance or transmittance of photons
- · Scan photon energies

Photoelectron

- Photon just needs enough energy to eject electron
- Measure kinetic energy of ejected electrons
- Monochromatic photon source

Why would a chemist care about ionizations anyway?

- Models for description of electronic structure are typically based on an orbital approximation.
- Tjalling C. Koopmans, "Ordering of Wave Functions and Eigenvalues to the Individual Electrons of an Atom." Physica 1933, 1, 104

 Koopmans' Theorem: "The negative of the energy of an occupied orbital from a theoretical calculation is equal to the vertical ionization energy due to the removal of an electron from that orbital."

$$\Psi = \prod_{i}^{N} \phi_{i} \qquad (I.E.)_{i} = -\varepsilon(\phi_{i})$$

Ionization is still a transition between states

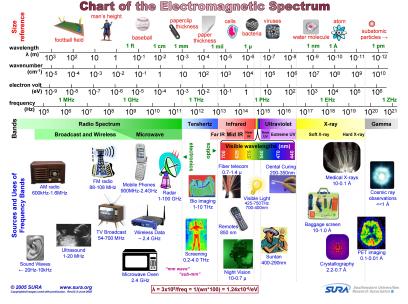
- Initial State: Neutral (or anion)
- Final State: Atom/Molecule/Anion after an electron is removed, plus the ejected electron
- M → M+ + e-
- · More on this next time

Historical Timeline

- First spectrophotometer: 1850s
- First IR:1880s
- First crystallography: 1912
- First NMR: 1938
- First EPR: 1944
- First PES: 1957

What took so long?

- Development of electron kinetic energy analyzers with sufficient resolution to be useful.
- Development of suitable sources of ionizing radiation – vacuum UV, soft X-ray
- · Development of electron detectors
- · Development of UHV technology

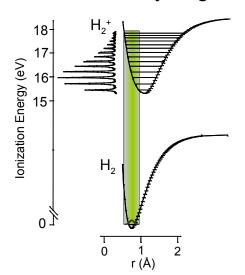


First Ionization Energies:

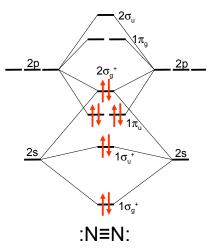
cesium ferrocene water 3.89 eV (319 nm) 7.90 eV (157 nm) 12.61 eV (98 nm)

- 4 ≣ > - 4

Potential Energy Surface Description of the lonization of Dihydrogen

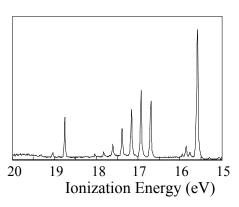


Consider Dinitrogen

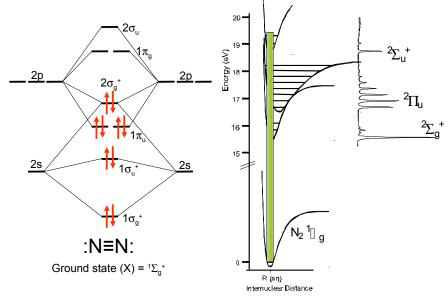


Ground state (X) = ${}^{1}\Sigma_{q}^{+}$

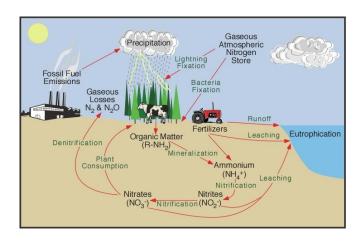
First ion state (X) = $^2\Sigma_g^+$ Second ion state (A) = $^2\Pi_u$ Third ion state (B) = $^2\Sigma_u^+$



Potential Well Description



Nitrogen Cycle



Nitrogen Cycle in the Oceans



The N₂ triple bond energy of 226 kcal/mol is nearly the strongest bond in chemistry

- For comparison, a typical N-N single bond energy is only 38
- Thus, it is more favorable to have N₂ than three N-N single
- In 1886 it was shown that N₂ can be "fixed" by certain
- In 1909 Haber's catalytic synthesis of NH₃ was discovered and

- The N₂ triple bond energy of 226 kcal/mol is nearly the strongest bond in chemistry
- For comparison, a typical N-N single bond energy is only 38 kcal/mol.
- Thus, it is more favorable to have N_2 than three N-N single bonds by 226-(3×38) = 112 kcal/mol!
- In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- In 1909 Haber's catalytic synthesis of NH₃ was discovered and industrialized rapidly with Bosch

- The N₂ triple bond energy of 226 kcal/mol is nearly the strongest bond in chemistry
- For comparison, a typical N-N single bond energy is only 38 kcal/mol.
- Thus, it is more favorable to have N_2 than three N-N single bonds by 226-(3×38) = 112 kcal/mol!
- In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- In 1909 Haber's catalytic synthesis of NH₃ was discovered and industrialized rapidly with Bosch

- The N₂ triple bond energy of 226 kcal/mol is nearly the strongest bond in chemistry
- For comparison, a typical N-N single bond energy is only 38 kcal/mol.
- Thus, it is more favorable to have N_2 than three N-N single bonds by 226-(3×38) = 112 kcal/mol!
- In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- In 1909 Haber's catalytic synthesis of NH₃ was discovered and industrialized rapidly with Bosch

- The N₂ triple bond energy of 226 kcal/mol is nearly the strongest bond in chemistry
- For comparison, a typical N-N single bond energy is only 38 kcal/mol.
- Thus, it is more favorable to have N_2 than three N-N single bonds by 226-(3×38) = 112 kcal/mol!
- In 1886 it was shown that N₂ can be "fixed" by certain organisms in root nodules
- In 1909 Haber's catalytic synthesis of NH₃ was discovered and industrialized rapidly with Bosch

- The first coordination complex with an N₂ ligand was reported in 1965 by Allan and Senoff
- N₂ shown to be a bridging ligand by Taube in 1968
- Binding of N_2 to d-block metals involves N_2 acting principally as a π -acceptor ligand

- The first coordination complex with an N₂ ligand was reported in 1965 by Allan and Senoff
- N₂ shown to be a bridging ligand by Taube in 1968
- Binding of N_2 to d-block metals involves N_2 acting principally as a π -acceptor ligand

- The first coordination complex with an N₂ ligand was reported in 1965 by Allan and Senoff
- \bullet N₂ shown to be a bridging ligand by Taube in 1968
- Binding of N_2 to d-block metals involves N_2 acting principally as a π -acceptor ligand

- 1903 electric arc furnace process
- $0.5 \text{ N}_2 + 1.25 \text{ O}_2 + 0.5 \text{ H}_2\text{O} \longrightarrow \text{HNO}_3$
- $\bullet \Delta H_{\rm ryn}^{\circ} = -30.3 \text{ kJ/mol}$
- High kinetic barrier leads to requirement for immense energy
- Otherwise, our atmosphere would be devoid of oxygen and the

- 1903 electric arc furnace process
- $0.5 \text{ N}_2 + 1.25 \text{ O}_2 + 0.5 \text{ H}_2\text{O} \longrightarrow \text{HNO}_3$
- $\bullet \Delta H_{\rm ryn}^{\circ} = -30.3 \text{ kJ/mol}$
- High kinetic barrier leads to requirement for immense energy
- Otherwise, our atmosphere would be devoid of oxygen and the

- 1903 electric arc furnace process
- $0.5 \text{ N}_2 + 1.25 \text{ O}_2 + 0.5 \text{ H}_2\text{O} \longrightarrow \text{HNO}_3$
- \bullet $\Delta H_{\rm ryn}^{\circ} = -30.3 \text{ kJ/mol}$
- High kinetic barrier leads to requirement for immense energy
- Otherwise, our atmosphere would be devoid of oxygen and the

- 1903 electric arc furnace process
- $0.5 \text{ N}_2 + 1.25 \text{ O}_2 + 0.5 \text{ H}_2\text{O} \longrightarrow \text{HNO}_3$
- \bullet $\Delta H_{
 m rxn}^{\circ} = -30.3 \ kJ/mol$
- High kinetic barrier leads to requirement for immense energy input to effect this reaction
- Otherwise, our atmosphere would be devoid of oxygen and the world's oceans would consist of dilute aqueous nitric acid!

- 1903 electric arc furnace process
- $0.5 \text{ N}_2 + 1.25 \text{ O}_2 + 0.5 \text{ H}_2\text{O} \longrightarrow \text{HNO}_3$
- ullet $\Delta H_{
 m rxn}^{\circ} = -30.3 \ kJ/mol$
- High kinetic barrier leads to requirement for immense energy input to effect this reaction
- Otherwise, our atmosphere would be devoid of oxygen and the world's oceans would consist of dilute aqueous nitric acid!

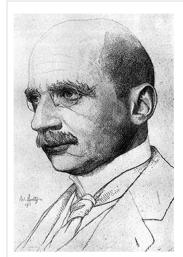
- Frank-Caro process, Cyanamide process, very energy intensive (1000 °C)
- $N_2 + CaC_2 \longrightarrow CaCN_2 + C$
- First decades of the 20th century, calcium cyanamide
- Odda, Norway had largest factory producing 12,000 ton/year

- \bullet Frank-Caro process, Cyanamide process, very energy intensive (1000 $^{\circ}\text{C})$
- $N_2 + CaC_2 \longrightarrow CaCN_2 + C$
- First decades of the 20th century, calcium cyanamide dominated the market for synthetic fertilizer
- Odda, Norway had largest factory producing 12,000 ton/year

- \bullet Frank-Caro process, Cyanamide process, very energy intensive (1000 $^{\circ}\text{C})$
- $\bullet \ \mathsf{N}_2 + \mathsf{CaC}_2 \longrightarrow \mathsf{CaCN}_2 + \mathsf{C}$
- First decades of the 20th century, calcium cyanamide dominated the market for synthetic fertilizer
- Odda, Norway had largest factory producing 12,000 ton/year

- \bullet Frank-Caro process, Cyanamide process, very energy intensive (1000 $^{\circ}\text{C})$
- $\bullet \ \mathsf{N}_2 + \mathsf{CaC}_2 \longrightarrow \mathsf{CaCN}_2 + \mathsf{C}$
- First decades of the 20th century, calcium cyanamide dominated the market for synthetic fertilizer
- Odda, Norway had largest factory producing 12,000 ton/year

Fritz Haber



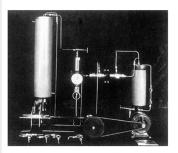
Fritz Haber, sketched in 1911 by W. Luntz.



Careful Studies of the Ammonia Equilibrium Graphic from the 1918 Nobel lecture

t (°C)	T (degr. abs.)	$\frac{P_{NH_3}}{P_{N2^{\frac{1}{2}}}P_{H2^{\frac{2}{2}}}}$	$-\log rac{P_{NH_3}}{P_{N_2}^{rac{1}{2}}P_{H_2}^{rac{1}{2}}}$	Percentage of NH_3 at equilibrium			
				at 1 atm	at 30 atm	at 100 atm	at 200 atm
200	473	0.1807	0.660	15.3	67.6	80.6	85.8
300	573	1.1543	0.070	2.18	31.8	52.1	62.8
400	673	1.8608	0.0138	0.44	10.7	25.1	36.3
500	773	2.3983	0.0040	0.129	3.62	10.4	17.6
600	873	2.8211	0.00151	0.049	1.43	4.47	8.25
700	973	3.1621	0.00069	0.0223	0.66	2.14	4.11
800	1,073	3.4417	0.00036	0.0117	0.35	1.15	2.24
900	1,173	3.6736	0.000212	0.0069	0.21	0.68	1.34
1,000	1,273	3.8679	0.000136	0.0044	0.13	0.44	0.87

Fritz Haber's Original Reactor



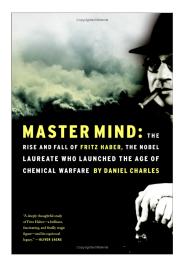
The laboratory apparatus designed by Fritz Haber and Robert Le Rossignol for producing ammonia from hydrogen and nitrogen, which was scaled up in the Haber-Bosch process. The catalytic process took place in the large cylinder on the left. Courtesy Archiv zur Geschichte der Max-Planck-Gesellschaft, Berlin-Dahlem.

Fritz Haber's Quest for Gold



Fritz Haber, third from the left, on board a ship to Buenos Aires. He hoped to mine the ocean's minuscule percentage of gold to pay Germany's reparations imposed by the Versailles treaty that signaled the end of World War I. Courtesy Archiv zur Geschichte der Max-Planck-Gesellschaft. Berlin-Dahlem.

Master Mind: A Fritz Haber Biography





- The ability to fix nitrogen is found in certain bacteria and archaea
- Biological nitrogen fixation requires complex enzyme systems and large expenditures of ATP
- Early crystallographic structure determinations of the nitrogenase enzyme suggested the presence of 7 three-coordinate iron centers in the iron-molybdenum cofactor (FeMo-co), thought to be the active site for N₂ binding and reduction
- Recent high-resolution structures have invalidated the three-coordinate iron hypothesis
- Read about nitrogenase at the protein data bank molecule of the month archive



- The ability to fix nitrogen is found in certain bacteria and archaea
- Biological nitrogen fixation requires complex enzyme systems and large expenditures of ATP
- Early crystallographic structure determinations of the nitrogenase enzyme suggested the presence of 7 three-coordinate iron centers in the iron-molybdenum cofactor (FeMo-co), thought to be the active site for N₂ binding and reduction
- Recent high-resolution structures have invalidated the three-coordinate iron hypothesis
- Read about nitrogenase at the protein data bank molecule of the month archive



- The ability to fix nitrogen is found in certain bacteria and archaea
- Biological nitrogen fixation requires complex enzyme systems and large expenditures of ATP
- Early crystallographic structure determinations of the nitrogenase enzyme suggested the presence of 7 three-coordinate iron centers in the iron-molybdenum cofactor (FeMo-co), thought to be the active site for N₂ binding and reduction
- Recent high-resolution structures have invalidated the three-coordinate iron hypothesis
- Read about nitrogenase at the protein data bank molecule of the month archive



- The ability to fix nitrogen is found in certain bacteria and archaea
- Biological nitrogen fixation requires complex enzyme systems and large expenditures of ATP
- Early crystallographic structure determinations of the nitrogenase enzyme suggested the presence of 7 three-coordinate iron centers in the iron-molybdenum cofactor (FeMo-co), thought to be the active site for N₂ binding and reduction
- Recent high-resolution structures have invalidated the three-coordinate iron hypothesis
- Read about nitrogenase at the protein data bank molecule of the month archive



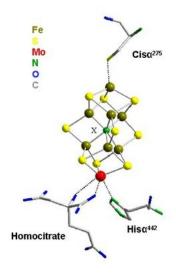
The Nitrogenase Enzyme

A large and complex metalloenzyme system

- The ability to fix nitrogen is found in certain bacteria and archaea
- Biological nitrogen fixation requires complex enzyme systems and large expenditures of ATP
- Early crystallographic structure determinations of the nitrogenase enzyme suggested the presence of 7 three-coordinate iron centers in the iron-molybdenum cofactor (FeMo-co), thought to be the active site for N₂ binding and reduction
- Recent high-resolution structures have invalidated the three-coordinate iron hypothesis
- Read about nitrogenase at the protein data bank molecule of the month archive



Current View of FeMo-co Structure





Schrock's Molybdenum Catalyst System

Department of Chemistry, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

*To whom correspondence should be addressed. E-mail: rrs@mit.edu

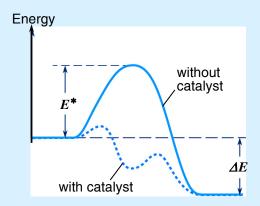
Scheme 1.

www.sciencemag.org SCIENCE VOL 301 4 IULY 2003

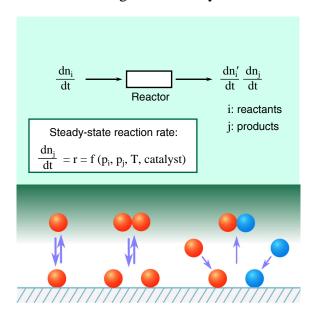
Fig. 1. Proposed intermediates in the reduction of dinitrogen at a [HIPTN₃N]Mo (Mo) center through the stepwise addition of protons and electrons.



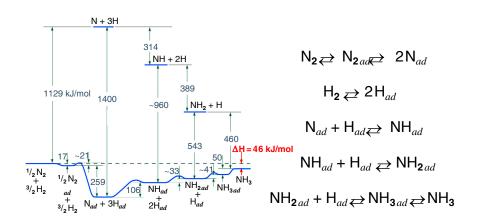
Progress of a chemical reaction



Heterogeneous catalysis



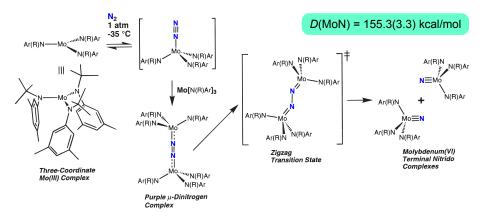
Mechanism of catalytic ammonia synthesis



G. Ertl, Catal.Rev.Sci.Eng. 21 (1980), 201



Dinitrogen Cleavage by a Molybdenum Complex Laplaza and Cummins, 1995



Dinitrogen Hydrogenation and Cleavage by a Zirconium Complex

Nature 427, 527-530 (05 Feb 2004), doi: 10.1038/nature02274

letters to nature

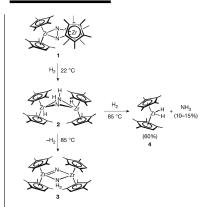


Figure 1 Hydrogenation and cleavage of No.

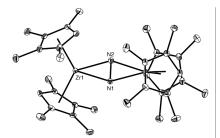


Figure 2 X-ray crystal structure of $\{\eta^5 - C_3 M c_4 H_2 Z T_2 (\mu_2, \eta^2, \eta^2 - N_2) (1)\}$. Molecular structure at 30% probability ellipsoids, with hydrogen atoms omitted for clarity, Selected bond lengths and angles: N(1) - N(2): 1.377(3) \hat{A} , Z(1) - N(1): 2.118(1) \hat{A} , Z(1) - N(2): 2.311(1) \hat{A} , Z(1) - N(1): 2.119(1) \hat{A} , Z(1) - N(2): 2.311(1) \hat{A} , Z(1) - N(2): 37.81(9)°, N(2) - N(1) - Z(1): 17.57(7)°, N(2) - N(1) - Z(1): 7.56(7)°, Z(1) - N(1) - Z(1): 7.16(7)°, Z(1) - N(2) - Z(1): 7.16(1)°, Z(1) - N(2) - Z(1): 7.17(1)°, Z(1) - N(2) - Z(1): 7.18(1)°, Z(1) - Z(1): 7.18(1)°,



■MOLECULE OF THE YEAR

NO News Is Good News

A startlingly simple molecule unites neuroscience, physiology, and immunology and revises scientists' understanding of how cells communicate and defend themselves

A decade ago, nitric oxide (NO) was just another toxic molecule, one of a lengthy list of environmental pol-lutants found in unsavory haunts such as cigarette smoke and smoze. Destrover

smoke and smog. Destroyer of ozone, suspected carcinogen, and precursor of acid rain, this gas had a bad reputation. But over the past 5 years, diverse lines of lar physiology, and carcinogenesis—suddenly realized they were studying the same molecule. Like a squirt of some powerful perfume, a puff of nitric oxide spurs different cells into an array of different activities, from communication to defense to regulation.

A thousand times NO. In 1992, scientists probed the reasons behind these multiple personalities. One significant clue: the biochemistry of nitric oxide manufacture. Cells rely

ing out how the enzyme works.

NO cure for heartache. This year, clini-

cal applications of NO knowledge bloomed in several directions at once, but much effort focused on nitric oxide's role as the body's own blood pressure police. In blood vessels, NO is released by endothelial cells on the inside of the vessel wall, migrates to nearby muscle cells, and relaxes them. This dilates the vessel and lowers blood pressure.



- Nitrous oxide, N2O, is known as laughing gas
- N₄O isolated in 1993 as a pale yellow solid
- NO₂ is a brown paramagnetic gas that dimerizes reversibly
- Nitrite is the [NO₂]⁻ anion
- Nitrate is the [NO₃]⁻ anion

- Nitrous oxide, N2O, is known as laughing gas
- N₄O isolated in 1993 as a pale yellow solid
- NO₂ is a brown paramagnetic gas that dimerizes reversibly
- Nitrite is the [NO₂]⁻ anion
- Nitrate is the [NO₃]⁻ anion

- Nitrous oxide, N2O, is known as laughing gas
- N₄O isolated in 1993 as a pale yellow solid
- ullet NO $_2$ is a brown paramagnetic gas that dimerizes reversibly
- Nitrite is the [NO₂]⁻ anion
- Nitrate is the [NO₃]⁻ anion

- Nitrous oxide, N2O, is known as laughing gas
- N₄O isolated in 1993 as a pale yellow solid
- ullet NO $_2$ is a brown paramagnetic gas that dimerizes reversibly
- Nitrite is the [NO₂]⁻ anion
- Nitrate is the [NO₃]⁻ anion

- Nitrous oxide, N2O, is known as laughing gas
- N₄O isolated in 1993 as a pale yellow solid
- ullet NO $_2$ is a brown paramagnetic gas that dimerizes reversibly
- Nitrite is the [NO₂]⁻ anion
- Nitrate is the [NO₃]⁻ anion