

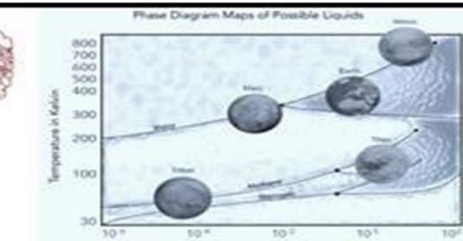
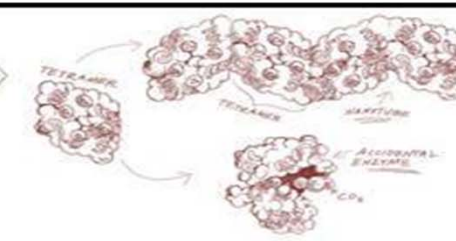
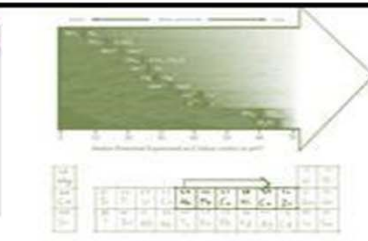
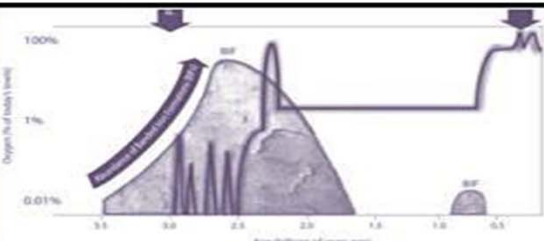
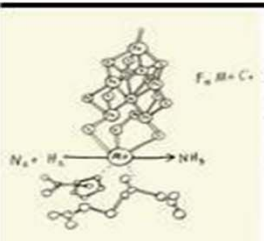
American Scientific Affiliation
Physical Sciences Section
July 2016

Ben McFarland
Professor of Biochemistry
Seattle Pacific University
benmcfarland.com

(and the brain)
^

What kind of book is A World From Dust?

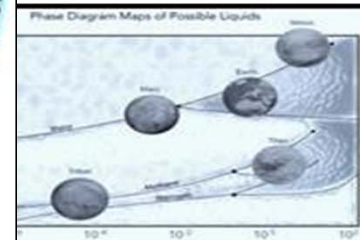
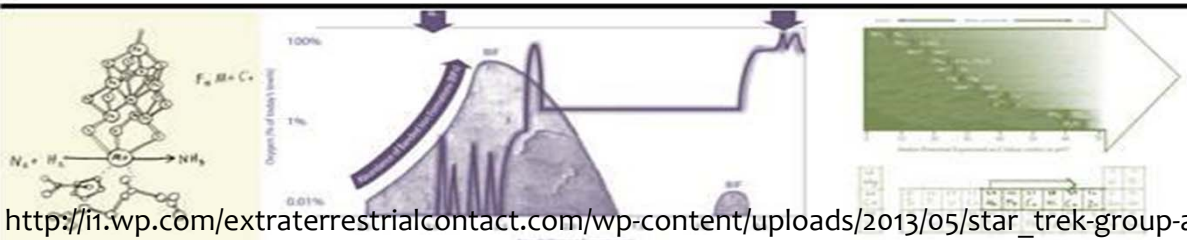
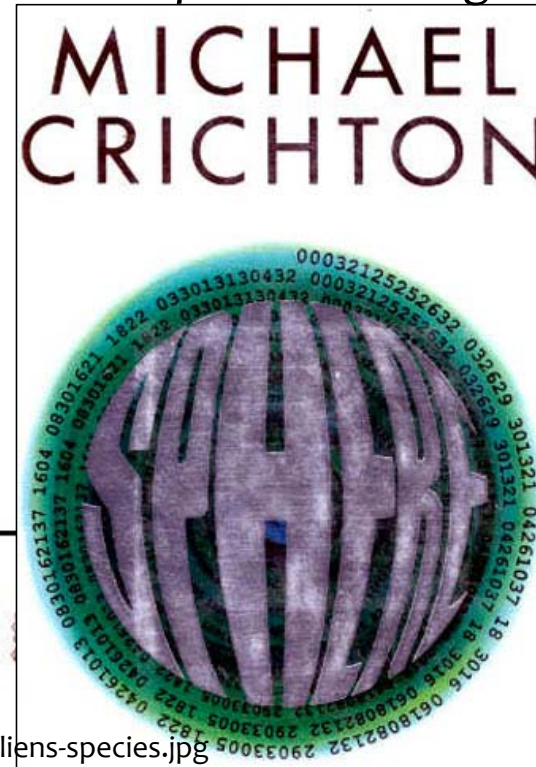
- * On the “Popular Science” shelf
- * Big (Natural) History
- * Adapted from a set of physical chemistry lectures
- * General hypothesis:
 - * Changes in chemistry can *constrain* or even *cause* changes in biology at all scales (including the planetary)
 - * Chapter 10 is about how chemistry shaped the brain



Would brain chemistry be the same on a different planet?

* Two hypotheses of alien evolution:

Star Trek = convergent evolution // Michael Crichton's *Sphere* = divergent evolution

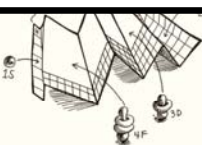






http://i1.wp.com/extraterrestrialcontact.com/wp-content/uploads/2013/05/star_trek-group-aliens-species.jpg

Q: What chemistry do brains use on *this* planet, and why?

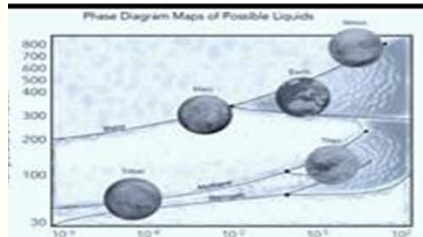
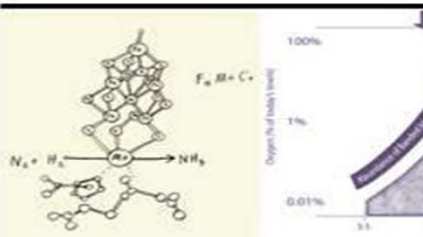
Start with the observation that only a subset of the periodic table is used by life

FOLDING PERIODIC TABLE

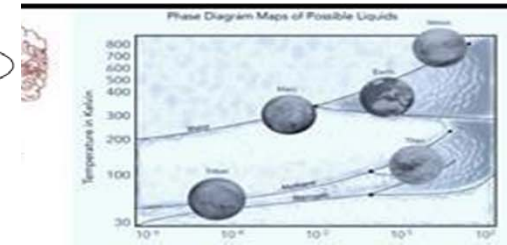
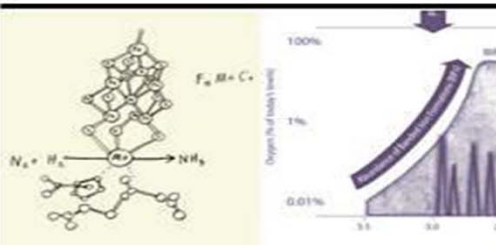
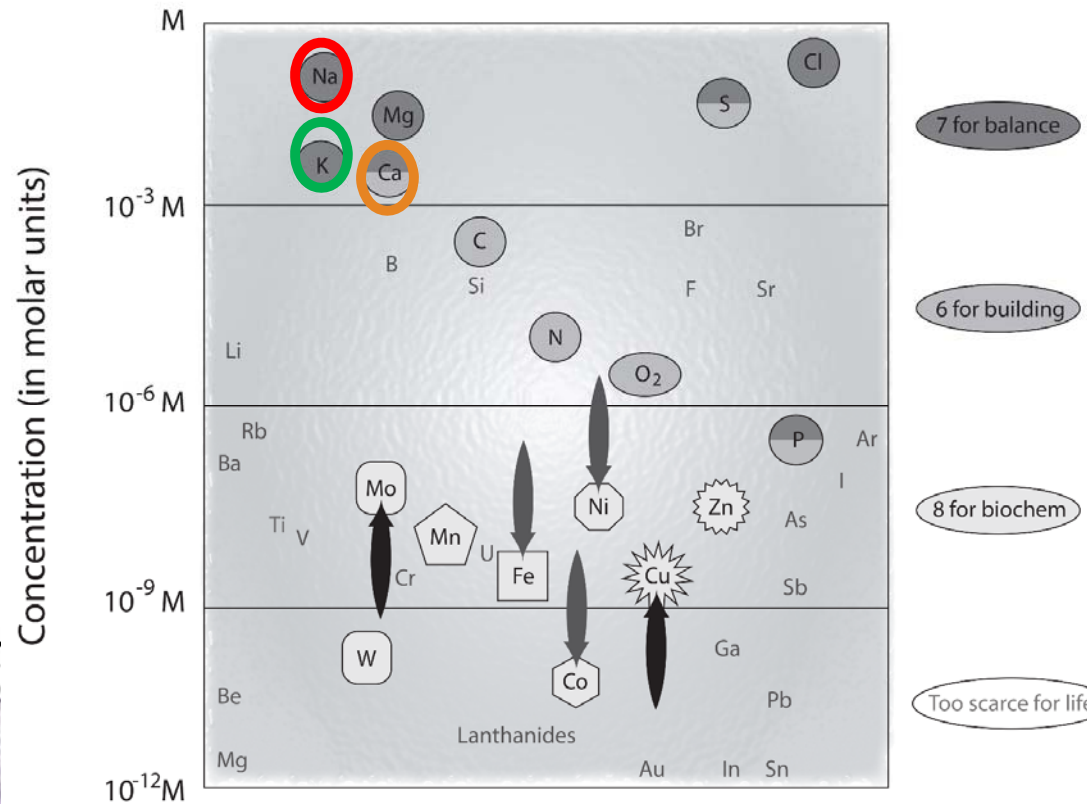


-  = ELEMENTS FOR BIOCHEMICAL BALANCE.
-  = ELEMENTS FOR BIOCHEMICAL BUILDING.
-  = ELEMENTS FOR BIOCHEMICAL CATALYSIS.
-  = ELEMENTS WITH CAPACITY FOR BOTH BUILDING + BALANCE

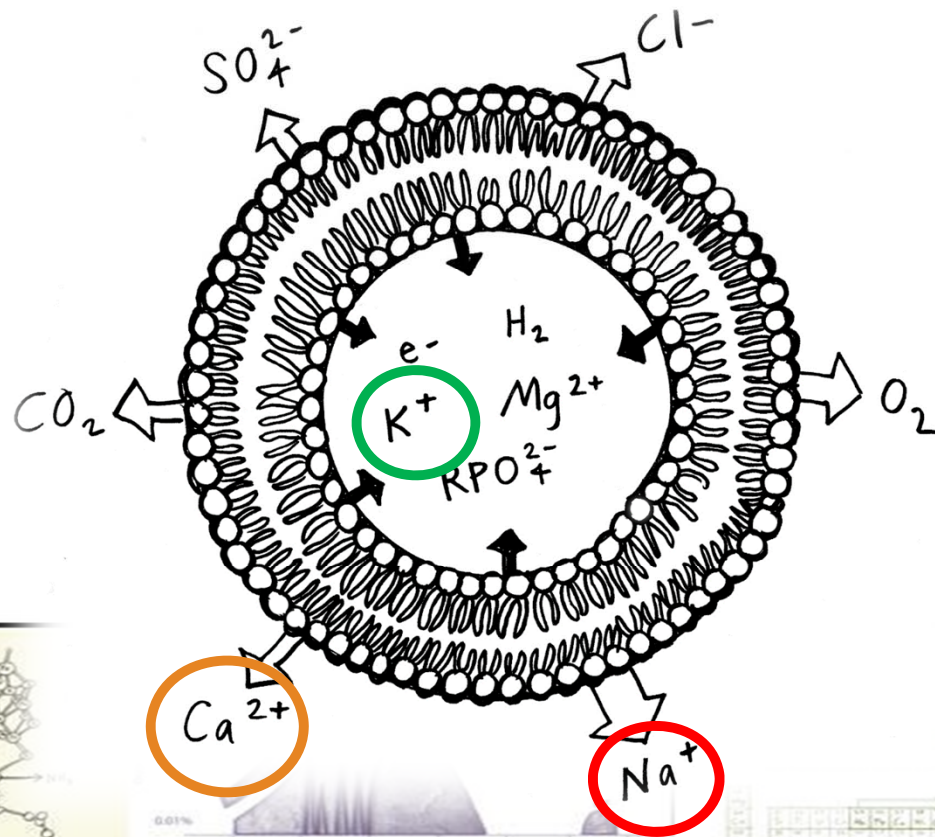
1s		4f RARE-EARTH METALS										3d TRANSITIONAL METALS										2p		2																																							
1	H																					5	6	7	8	9	10																																				
2	Li	3	Be																					13	14	15	16	17	18																																		
3	Na	4	Mg																					19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36																						
4	K	5	Ca																					37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54																						
5	Rb	6	Sr																					55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86								
6	Cs	7	Ba	8	La	9	Ce	10	Pr	11	Nd	12	Pm	13	Sm	14	Eu	15	Gd	16	Tb	17	Dy	18	Ho	19	Er	20	Tm	21	Yb	22	Lu	23	Hf	24	Ta	25	W	26	Re	27	Os	28	Ir	29	Pt	30	Au	31	Hg	32	Tl	33	Pb	34	Bi	35	Po	36	At	37	Rn
7	Fr	8	Ra	9	Ac	10	Th	11	Pa	12	U	13	Np	14	Pu	15	Am	16	Cm	17	Bk	18	Cf	19	Es	20	Fm	21	Mh	22	No	23	Lr	24	Rf	25	Db	26	Sg	27	Bh	28	Hs	29	Mt	30	Ds	31	Rg	32	Cn	33	Uut	34	Uuq	35	Uup	36	Uuq	37	Uus	38	Uuo



Each element has a job related to its *availability* in the ocean



Some available elements were used by cells, while others were pumped out and *rejected*

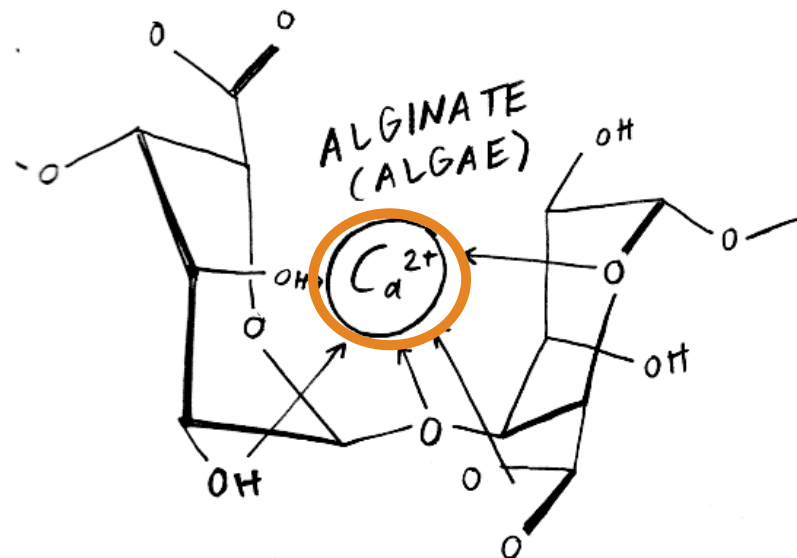


Chemical reasons why:

Mg^{+2} is kept in to balance the PO_4^- in DNA, but Ca^{+2} is too sticky and is rejected

K^+ (less common) is kept in and Na^+ (more common) is rejected for osmotic balance

Calcium has two + charges, which makes it strong enough to crosslink – charges on sugars

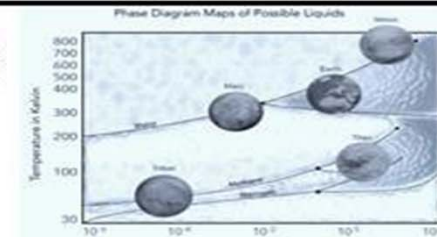


This allows it to form structures that single + charges like sodium and potassium cannot

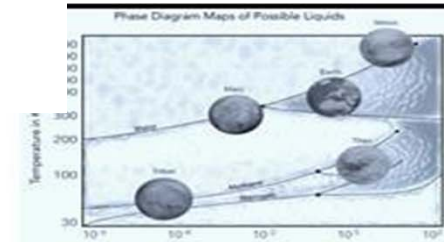
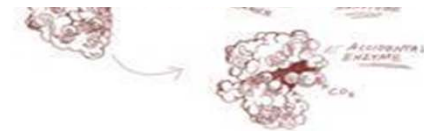
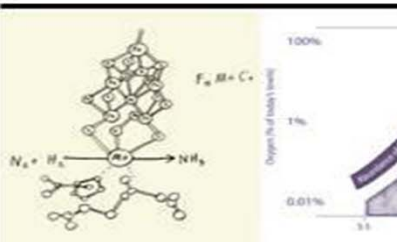
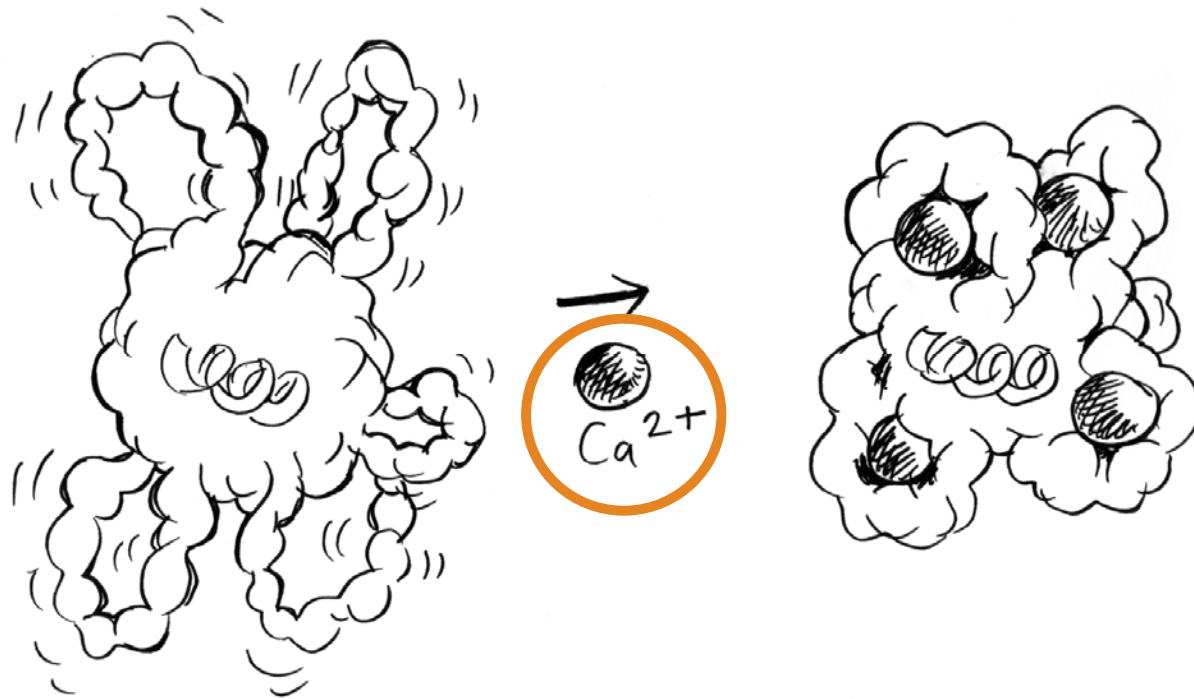
Alginate + calcium + liquid (like tea) =
spherification chemistry (~ cell wall)



https://upload.wikimedia.org/wikipedia/commons/1/13/Esferificaci%C3%B3n_de_T%C3%A9.jpg

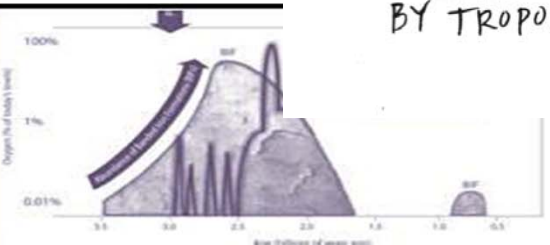
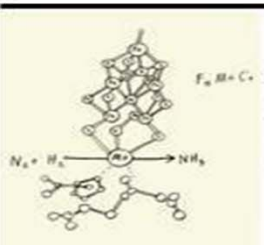
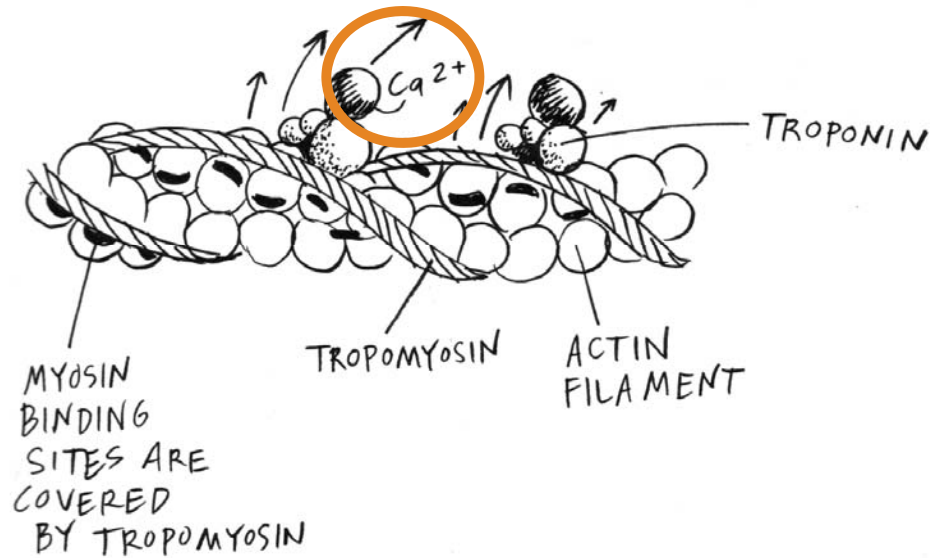


Calcium + dynamic protein = calcium-bound
solid protein = biological signal

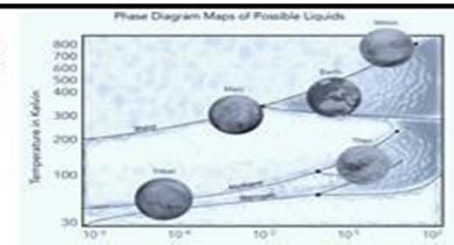
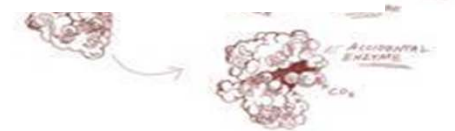


Calcium + muscle proteins = differently shaped proteins = physical movement

Ca^{2+} PULLS AWAY TROPOMYOSIN TO REVEAL MYOSIN BINDING SITES



Periodic table of elements.





Calcium has optimal kinetics for transient signals and shape changes

Sodium and potassium are faster-on and faster-off

Calcium is the only element that is fast-on and medium-off

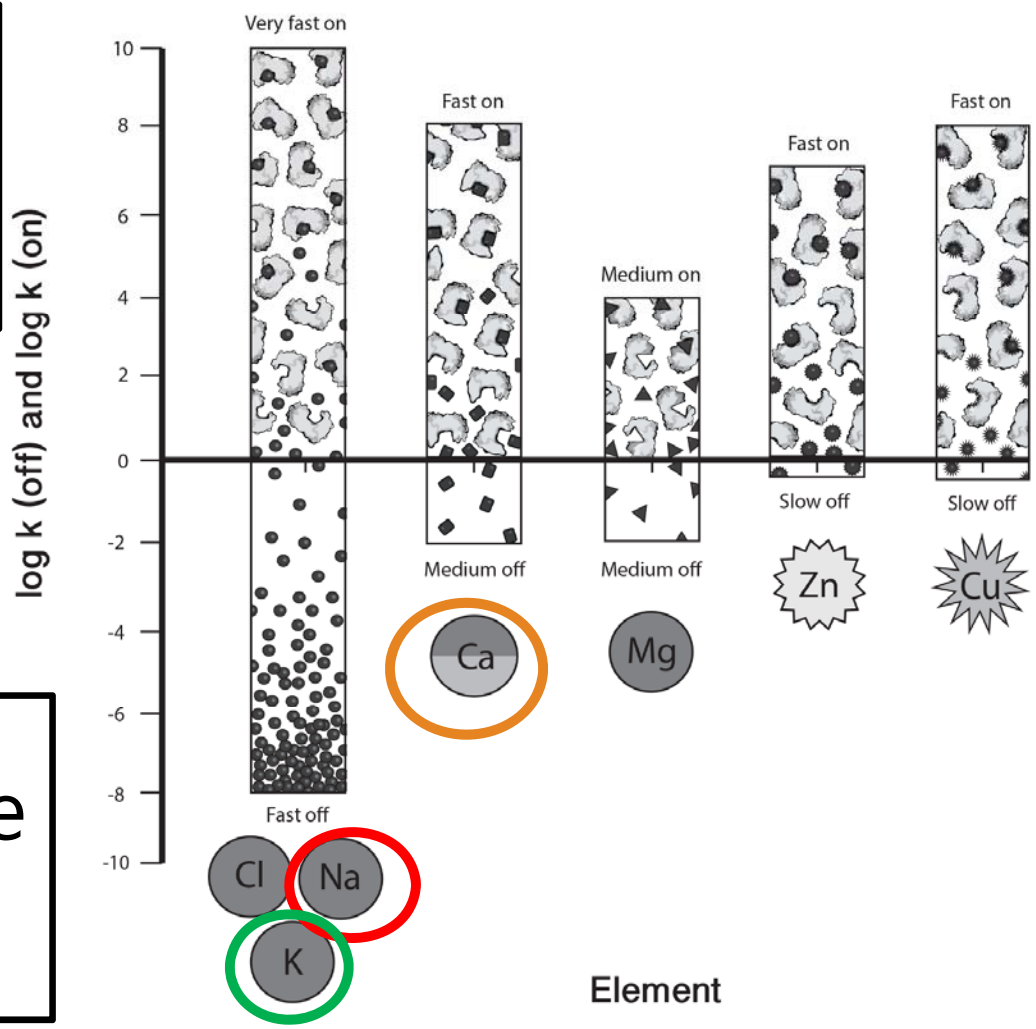
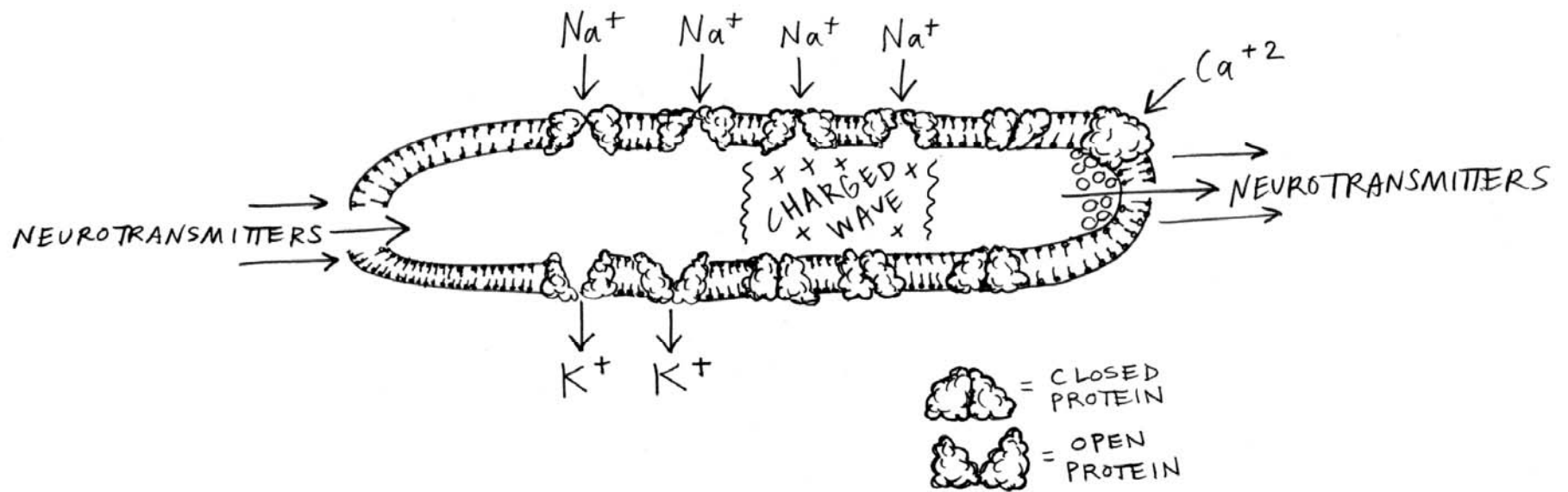
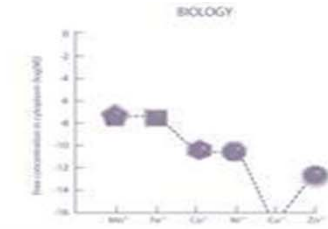
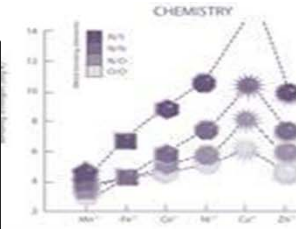


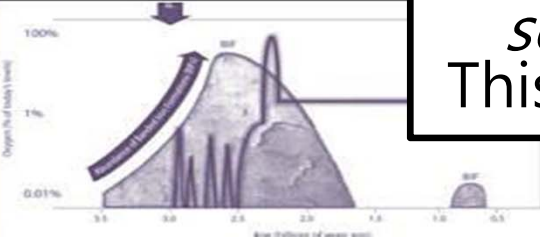
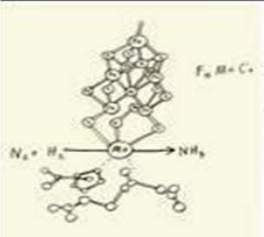
Figure 10.2: Binding speed of different elements



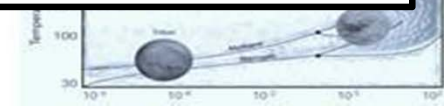
At the end of a neuron, calcium is used to move neurotransmitters out



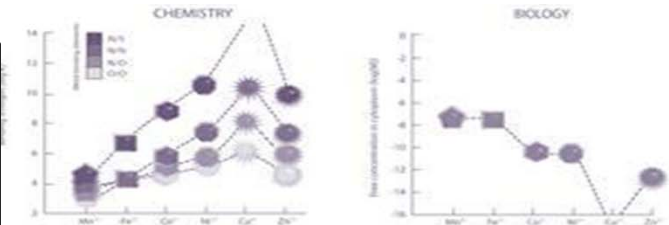
Along the length of a neuron, fast waves of *sodium in* and *potassium out* send a signal. This works because of the previous imbalances!



A grid or table with various symbols and numbers, possibly representing a periodic table or a data table. The symbols include letters and numbers in boxes.



A calcium sensor in your brain detects calcium waves and makes neurons fire more easily



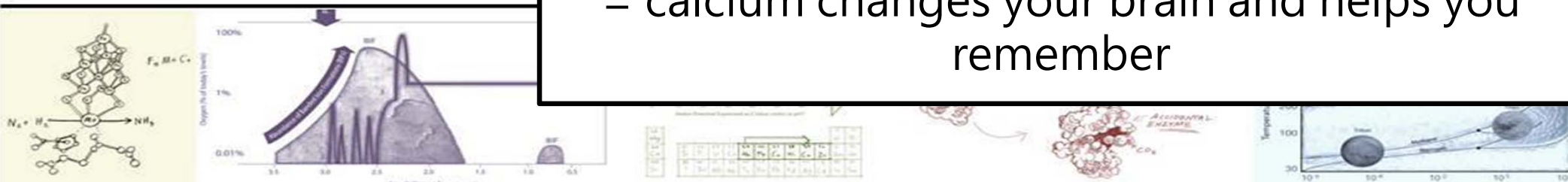
LETTER

doi:10.1038/nature16507

The calcium sensor synaptotagmin 7 is required for synaptic facilitation

Skyler L. Jackman¹, Josef Turecek¹, Justine E. Belinsky¹ & Wade G. Regehr¹

= calcium changes your brain and helps you remember



Chemistry is important. For example, chemical ions can *cause* sleep and wakefulness

NEUROSCIENCE

Ionic control of sleep and wakefulness

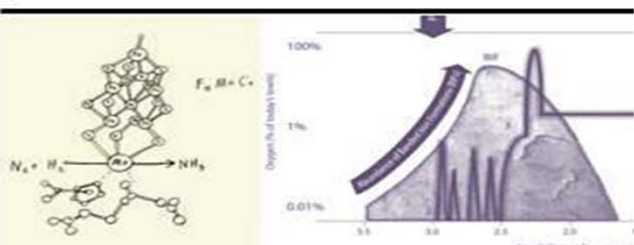
The ionic composition of brain fluid is linked to neuronal activity and sleep

By Hans-Peter Landolt^{1,2} and Sebastian C. Holst^{1,2}

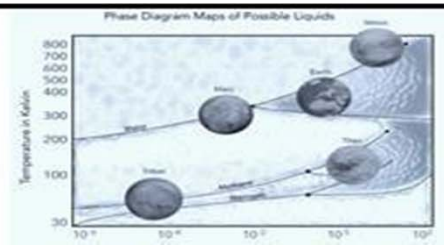
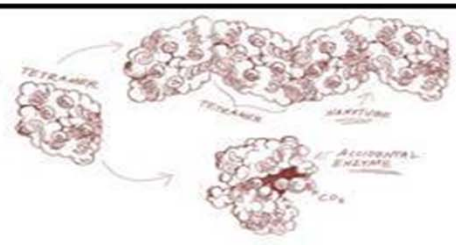
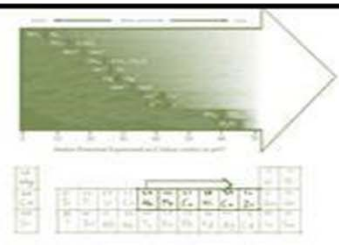
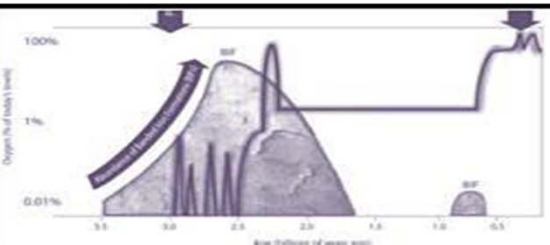
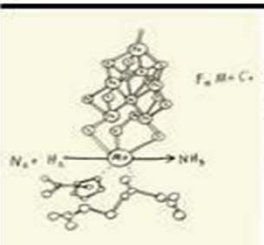
SLEEP RESEARCH

Changes in the composition of brain interstitial ions control the sleep-wake cycle

Fengfei Ding,^{1,2*} John O'Donnell,^{1*} Qiwu Xu,¹ Ning Kang,¹ Nanna Goldman,¹ Maiken Nedergaard^{1,3,†}



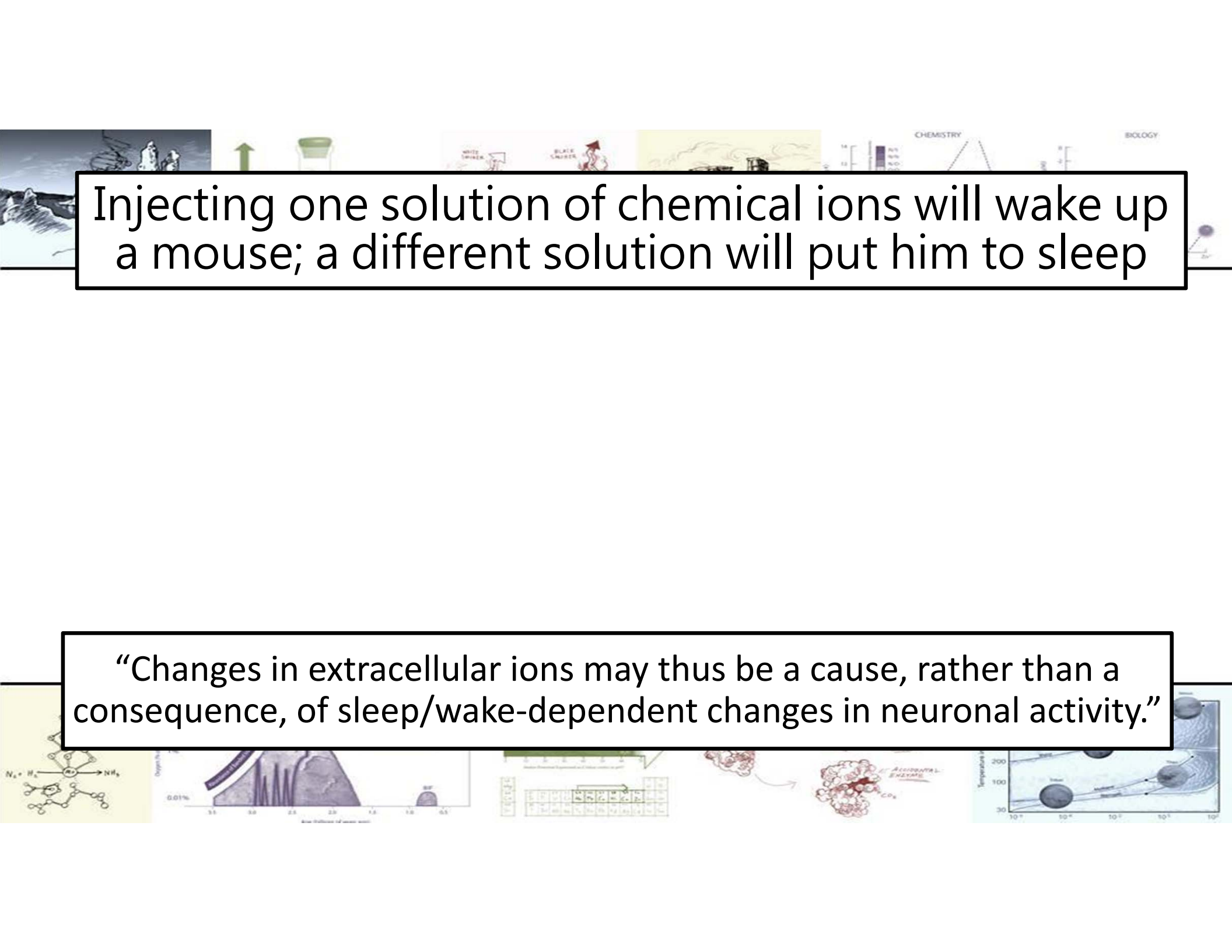
Chemical ions outside the neurons increase or decrease when a mouse wakes up





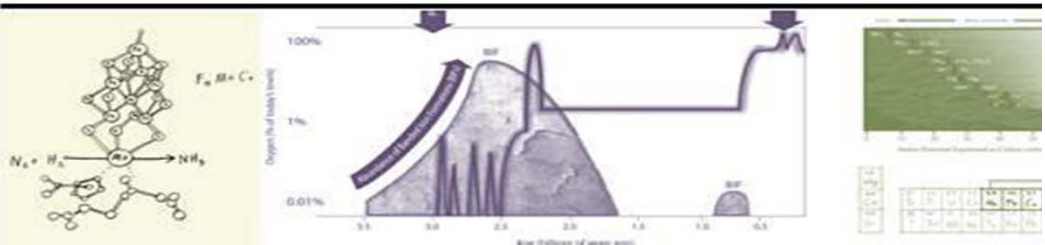
Injecting one solution of chemical ions will wake up a mouse; a different solution will put him to sleep

“Changes in extracellular ions may thus be a cause, rather than a consequence, of sleep/wake-dependent changes in neuronal activity.”





Magnesium and zinc have similar kinetics to calcium, and they are used for *other* signals



Calcium is the only element that is fast-on and medium-off

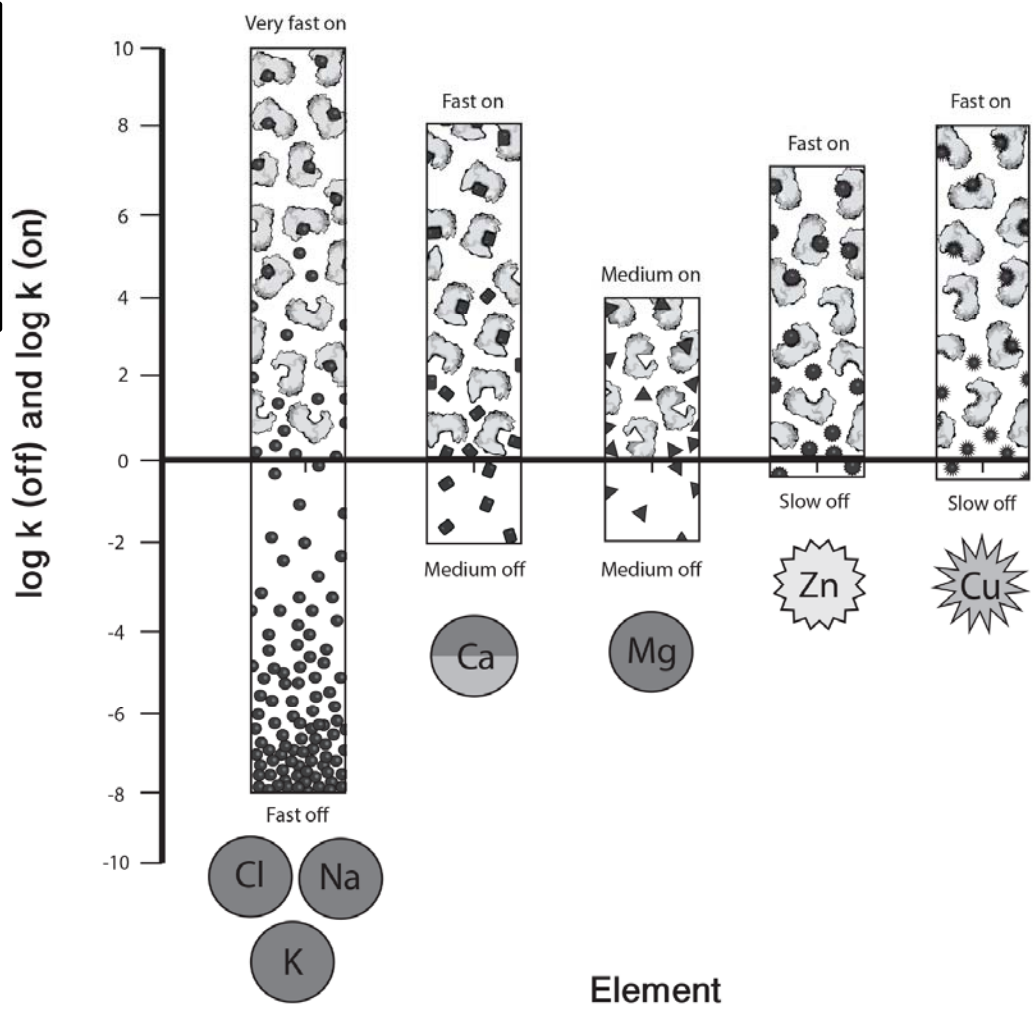


Figure 10.2: Binding speed of different elements

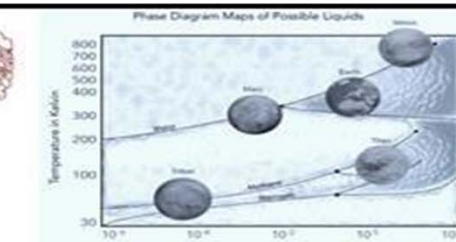
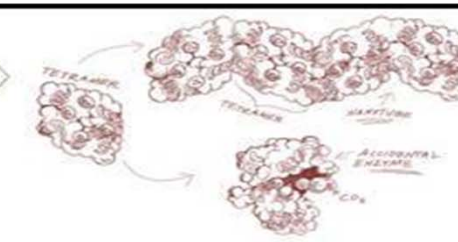
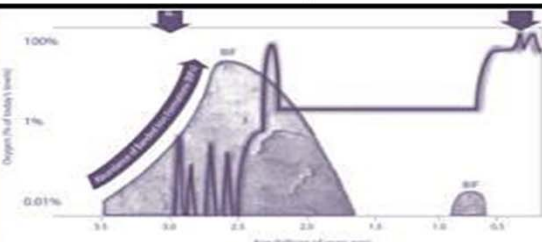
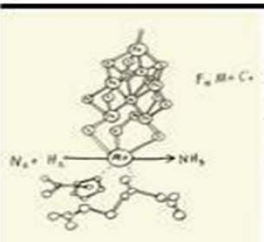
When a sperm cell fertilizes an egg cell, a wave of zinc is released

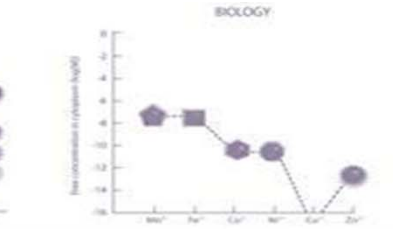
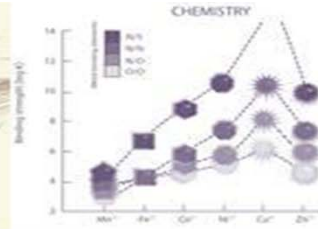
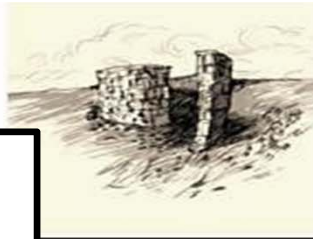
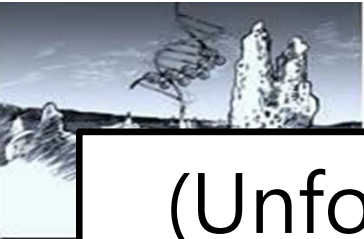
SCIENTIFIC REPORTS

OPEN

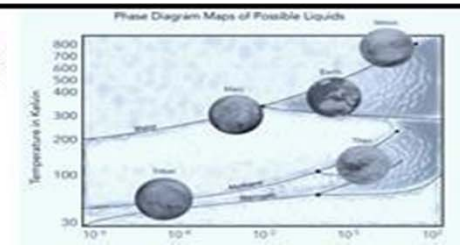
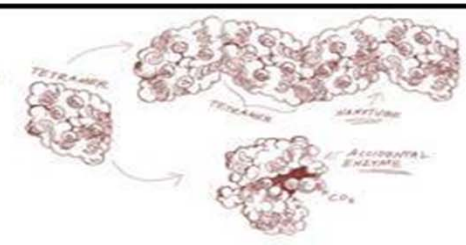
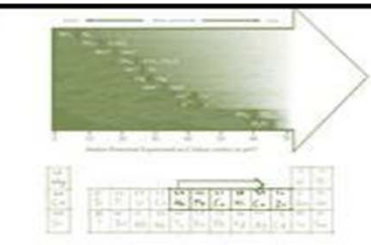
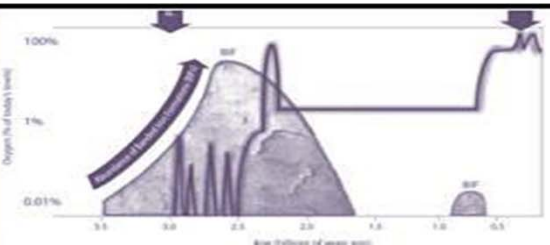
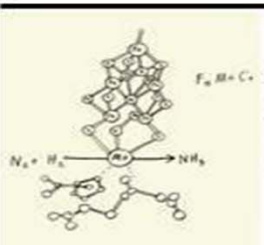
The zinc spark is an inorganic signature of human egg activation

Francesca E. Duncan^{1,*}, Emily L. Que^{2,*}, Nan Zhang^{1,*}, Eve C. Feinberg³,
Thomas V. O'Halloran^{2,4} & Teresa K. Woodruff¹



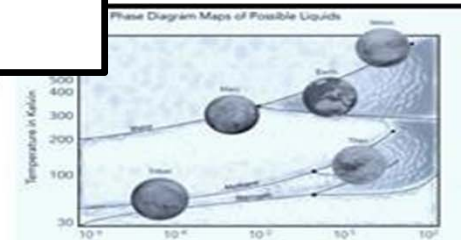
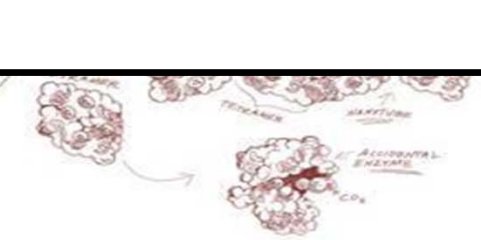
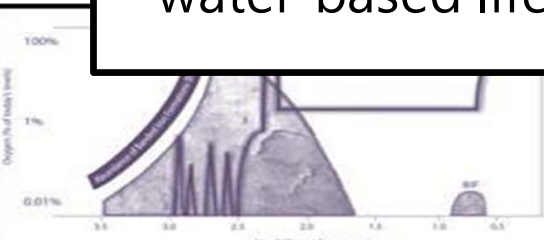
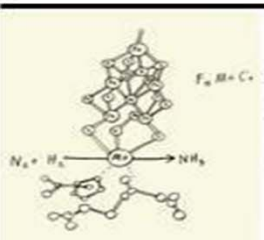
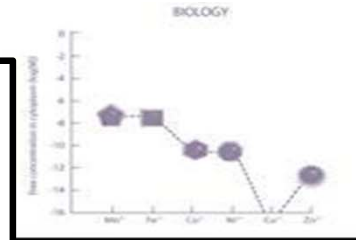


(Unfortunately, this was widely reported as a flash of light, but it is really zinc)



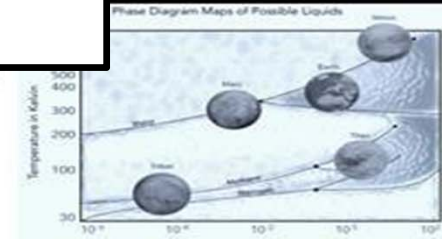
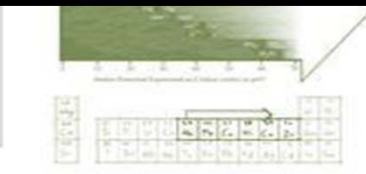
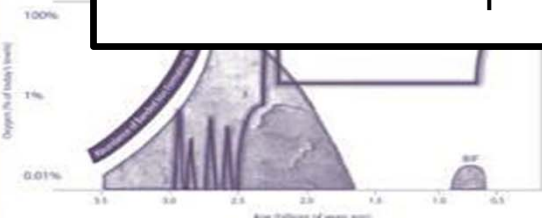
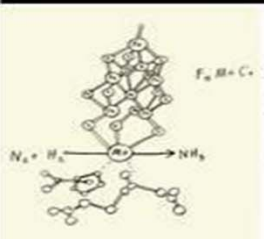
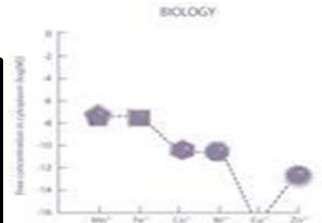
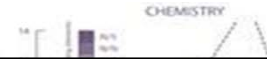
Much of the inorganic chemistry of the brain is predictable from the kinetics of different elements

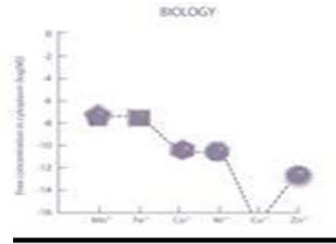
- * Calcium moves neurotransmitters
- * Sodium and potassium send positive waves
- * Calcium, potassium, and magnesium send wake/sleep signals
- * Zinc sends secondary/developmental signals
- * Because these result from the periodic table, **these jobs are likely to be universal** and common to all water-based life.



Much of the inorganic chemistry of the brain is predictable from the kinetics of different elements

- * *Star Trek* wins the nod in this area over Michael Crichton
- * Many chemical paths could never be taken by life because of the story of which chemicals were available when
- * Biological randomness is real, but is constrained by chemical order.
- * **A world that makes sense** is a world in which we can retrace our steps and be responsible for our future.

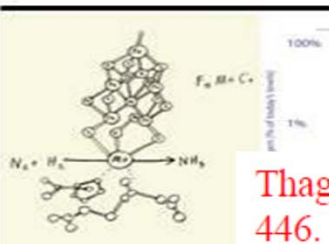




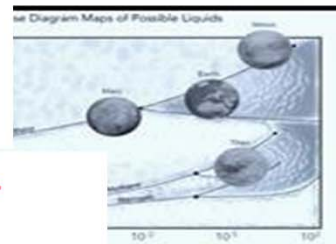
How Molecules Matter to Mental Computation

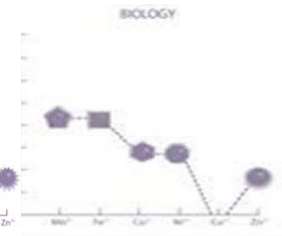
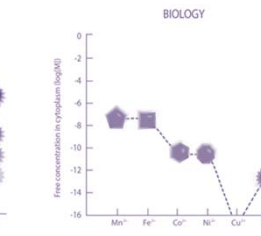
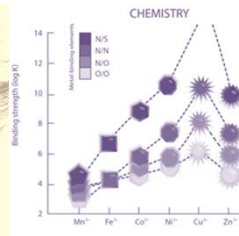
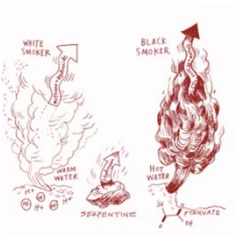
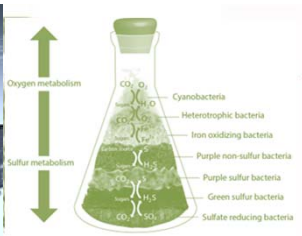
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Almost all computational models of the mind and brain ignore details about neurotransmitters, hormones, and other molecules. The neglect of neurochemistry in cognitive science would be appropriate if the computational properties of brains relevant to explaining mental functioning were in fact electrical rather than chemical. But there is considerable evidence that chemical complexity really does matter to brain computation, including the role of proteins in intracellular computation, the operations of synapses and neurotransmitters, and the effects of neuromodulators such as hormones. Neurochemical computation has implications for understanding emotions, cognition, and artificial intelligence.



Thagard, P. (2002). How molecules matter to mental computation. *Philosophy of Science*, 69, 429-446.





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