OSHER LIFELONG LEARNING INSTITUTE

OLLI AT ILLINOIS

Molecular Literacy for All

making sense of the “monstrous and boundless thicket” of everyday chemistry

Every breath I take…the molecules in the air we breathe are used to teach a model for atomic bonding.

ILLINOIS
Beckman Institute for Advanced Science & Technology

Jeff Moore (email: jsmoore@Illinois.edu)

Today's Outline

Connecting Atoms to Make Molecules

- The Octet Rule
- Covalency and electron pairs
- Exceeding the shell capacity is Not Allowed
- Valency of the Atoms (Carbon vs. Oxygen)
- Multiple Bonds Between Atom Pairs
- Electron Pair Domains

Oxygen and the Energy that Fuels You

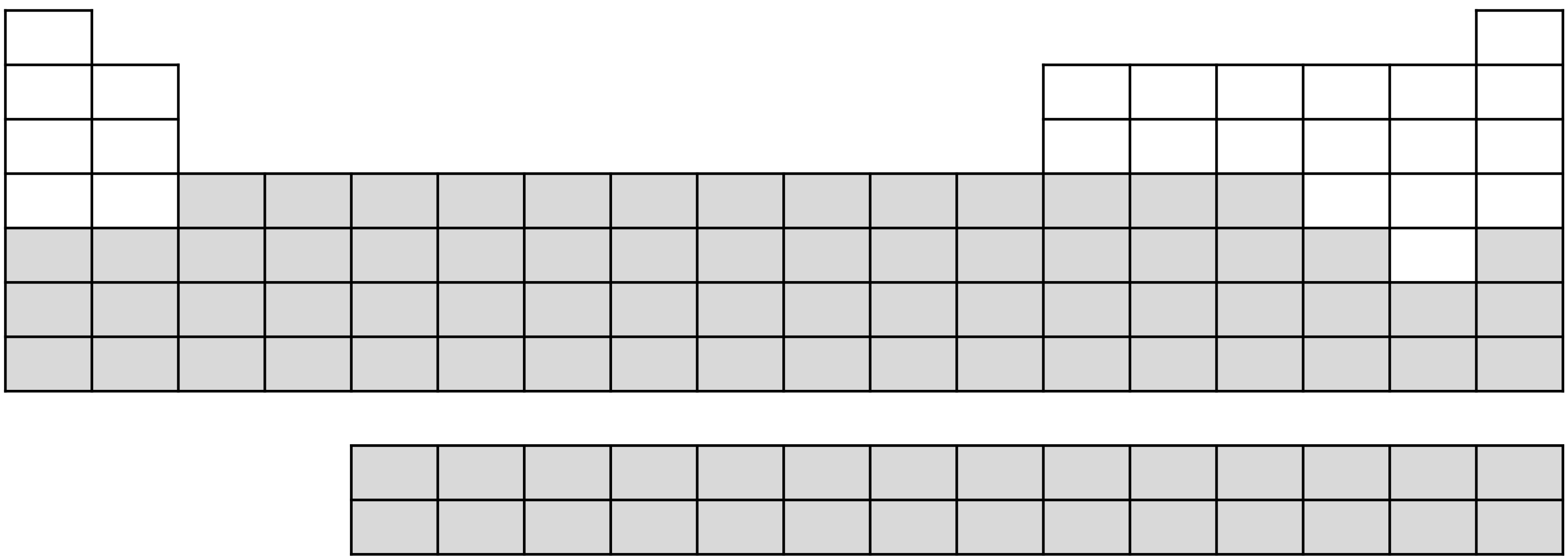
- Photosynthesis and respiration
- Tracking electrons in life's chemical symbiosis

Bonding Patterns

Charge of the Whole Molecule

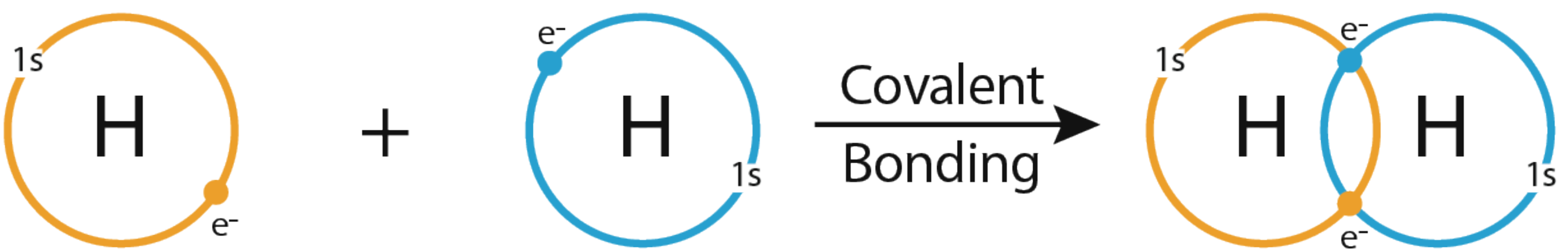
Satisfying an atom's electron count

- The *electron count* is the total number electrons in the valence shell of an atom
- Atoms gain or lose electrons to achieve the valence electron count of its nearest noble gas
- Nearest noble gas for H, He, Li, Be ⇒ 2 valence electrons
- Nearest noble gas for B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Cl, Ar, Se, ⇒ 8 valence electrons
- Indicate the charge on each atom that gives it a filled shell
- Show the valence electrons as dots



Molecular dihydrogen: the most common molecule in the universe

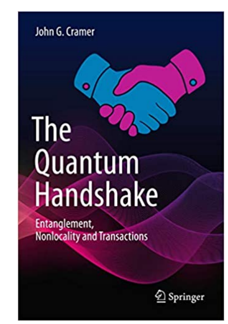
Covalency: The prefix *co-* means *jointly, associated in action, partnered to a lesser degree,* etc.; thus a "co-valent bond", in essence, means that the atoms share "valence"



The dihydrogen molecule, H_2

Truth table

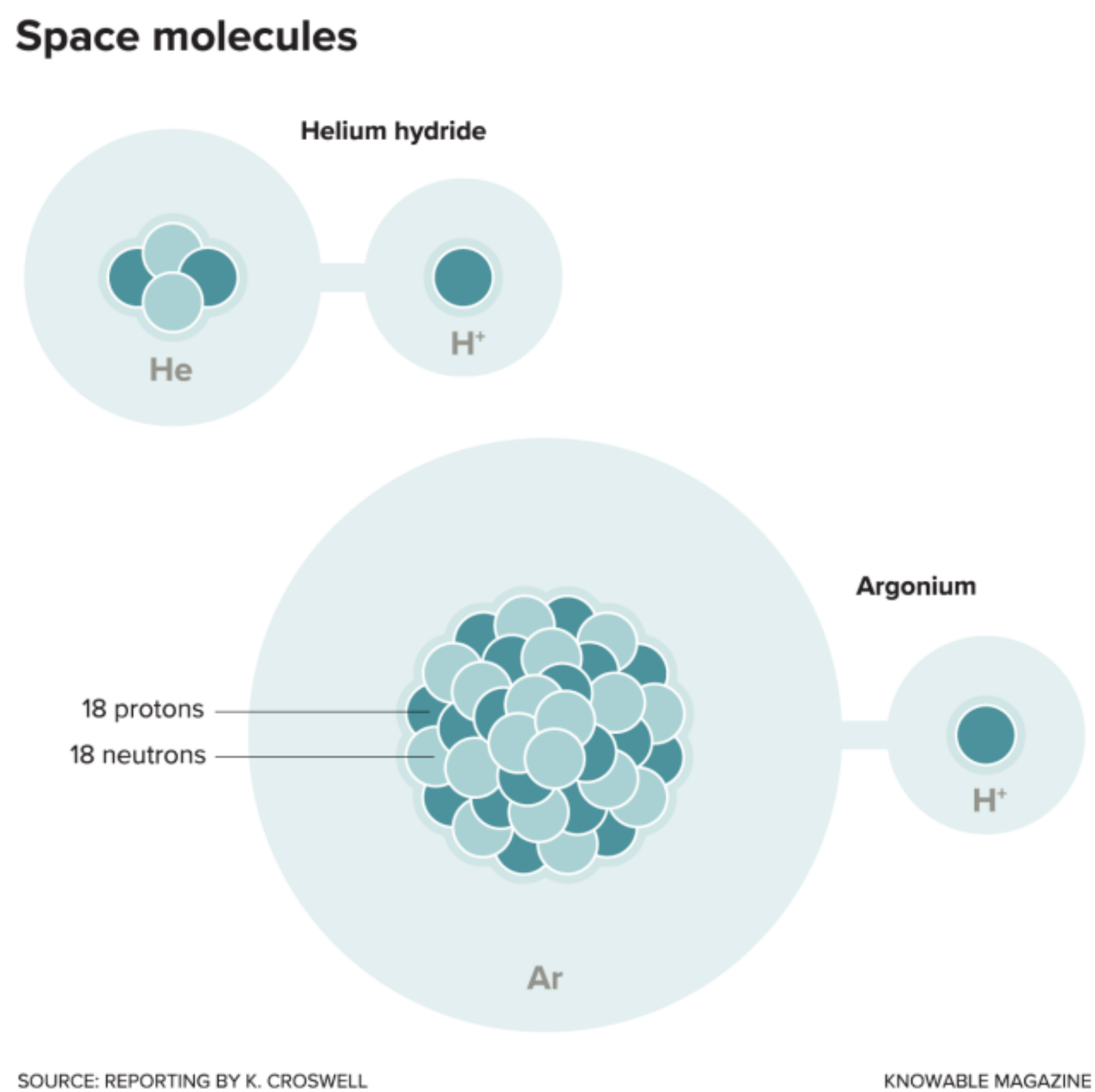
Subshell	No. e^-	Filled
1s	2	T
1s	2	T



By sharing, or pooling, their valence electrons, each nuclei counts a filled shell of electrons.
The electrons pair together to make a covalent bond.
The electrons in an electron pair have a special relationship. They engage in *The Quantum Handshake.*

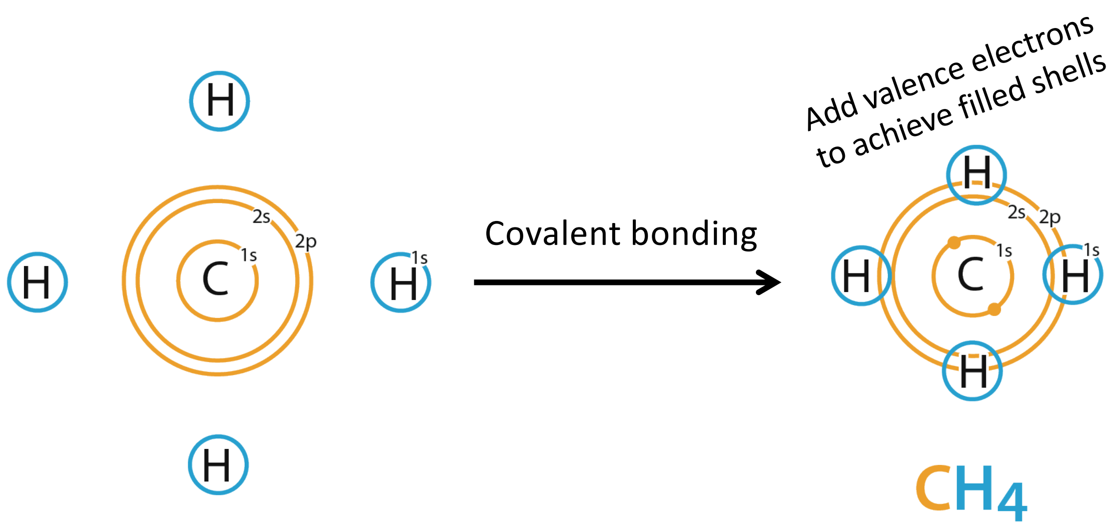
The Universe's First Molecule

The molecule arose because hydrogen and helium were the two chief elements to emerge from the big bang. At the beginning, the universe was so hot that any electrons either element managed to capture would immediately be stripped away by high-energy radiation generated by the extreme heat. But as space expanded, it cooled, and about 100,000 years after the big bang, each helium nucleus grabbed two electrons and became neutral. Put H^+ and He together and you have the universe's first molecule, HeH^+.

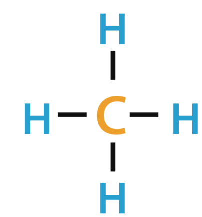


Methane teaches how heavier atoms acquire filled shells through covalent bonding

An electron count of eight fills the valence shell for B, C, N, O, F, and Ne (these are atoms of elements that reside in the second row of the periodic table).



Subshell	No. e^-	Filled
1s	2	T
2s	2	T
2p	6	T



The methane molecule

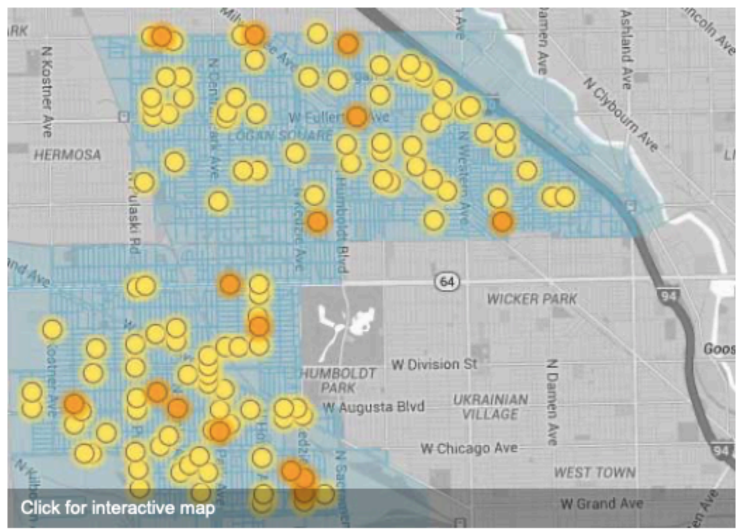
By pooling valence electrons, then dividing the pool into pairs, then properly distributing them between the valence subshells, four hydrogen atoms and one carbon atom combine to make one CH_4 (i.e., a methane molecule).

Methane is a greenhouse gas in our everyday life

Chicago: Snapshot of natural gas leaks under city streets

Leaked natural gas — mostly methane — is a powerful contributor to climate change.

Explore Chicago map data



Findings

Our readings indicated an average of **leak for every three miles** we drove.

Readings are from September throug 2014 and may not reflect current leak repairs or other changes.

If you ever smell gas, or have any reason to suspect a say to immediately exit the building or area, then call tl more see the Peoples Gas safety page.

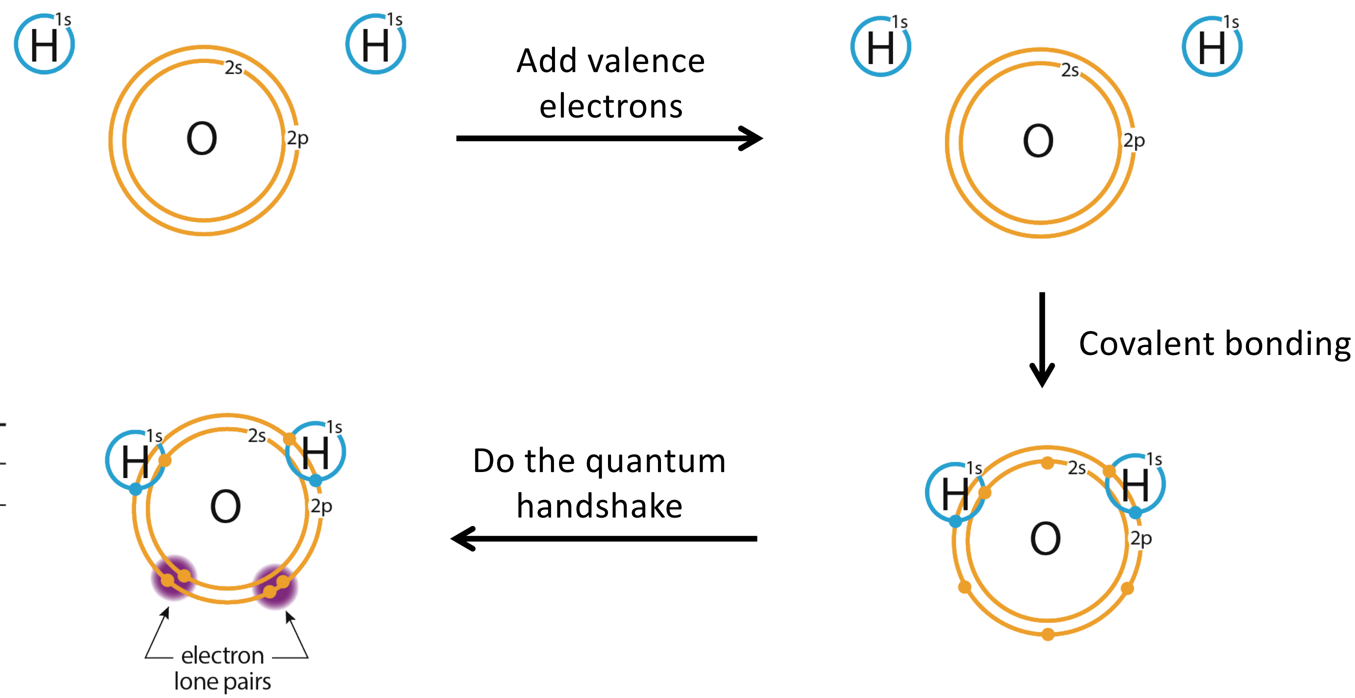
Hydrogen is a truncator atom

- A single covalent bond involves two electrons i.e., it’s one electron pair.
- Hydrogen completes its valence shell with just two electrons.
- Therefore, hydrogen is bonded to, at most, one-and-only-one other atom.
- Because hydrogen is bonded to just one atom, it serves as a truncator to block the sites on carbon that could otherwise go on and bond to other carbon atoms.
- This will become important when we talk about implicit hydrogen atoms; i.e., it is implied that the “unsubstituted sites” in molecular drawings are capped by hydrogen atoms, even if they are not explicitly shown.

Water (H_2O)

(did you ever wonder why water is H_2O and not something else, like H_6O?)

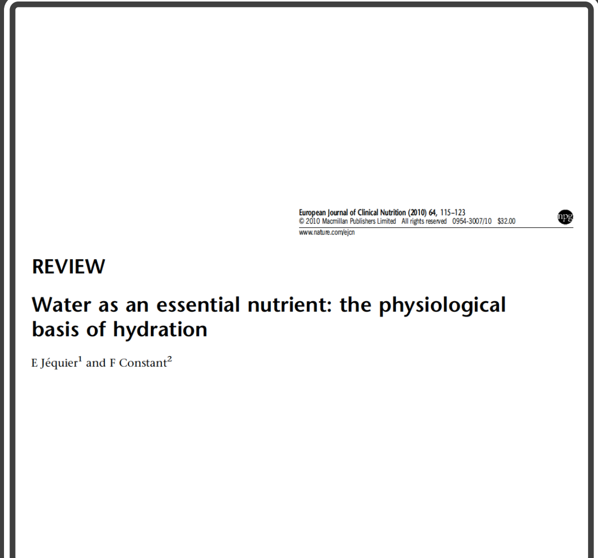
From here on, only valence electrons are shown



The water molecule

Subshell	No. e⁻	Filled
1s	2	T
2s	2	T
2p	6	T

H_2O

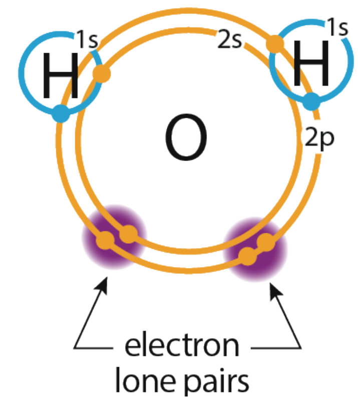

European Journal of Clinical Nutrition (2010) 64, 115–123

www.nature.com/ejcn

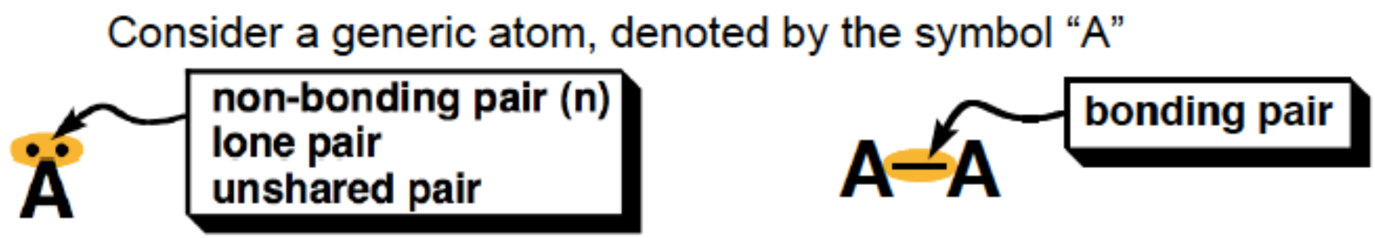
REVIEW

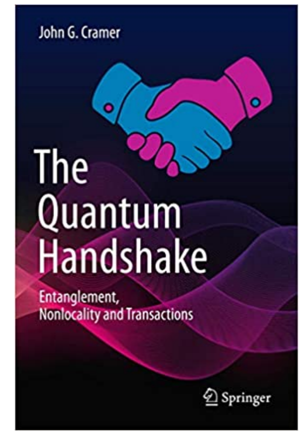
Water as an essential nutrient: the physiological basis of hydration

E Jéquier[1] and F Constant[2]



Water – an essential nutrient – teaches the concept of the electron lone pair





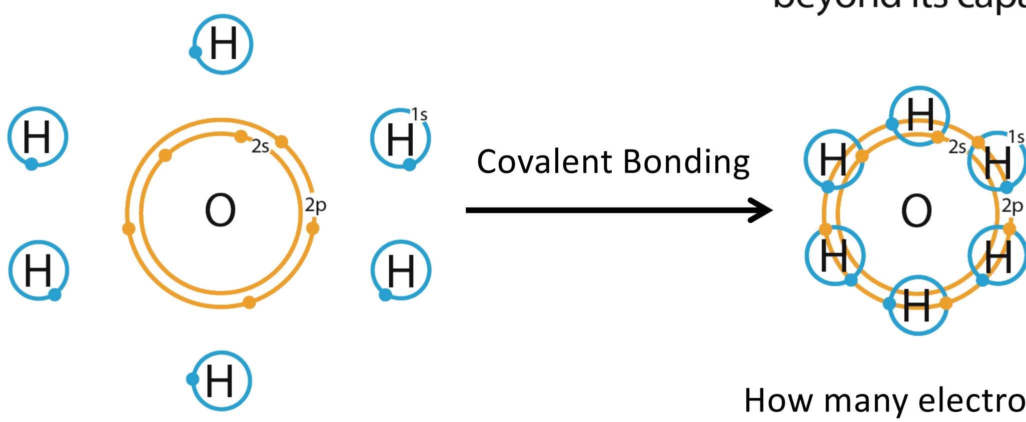
Electrons are usually paired

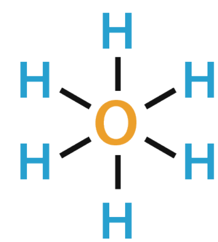
Valence-shell electron pairs come in two types: nonbonding and bonding. Nonbonding electrons, also called lone pairs or unshared pairs, are valence-shell electron pairs that are localized on only one atom. Bonding electrons are pairs of valence-shell electrons that are shared between two atoms.

Exceeding valence shell capacity

(Why water is H_2O and not something else (e.g., H_6O))

Shell #2 is filled beyond its capacity

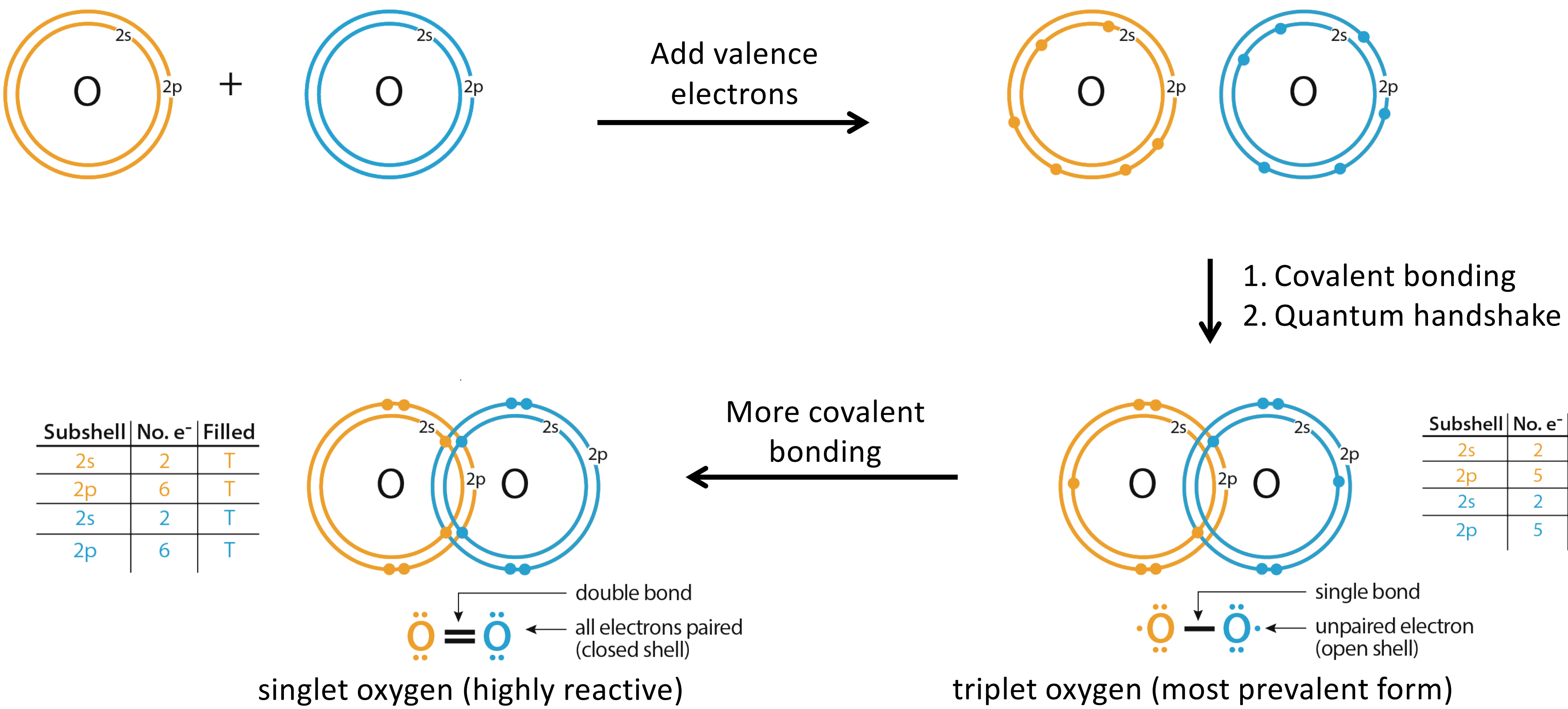




How many electrons are in oxygen's 2p subshell?

Subshell	No. e^-	Filled
1s	2	T
2s	2	T
2p	10	F

Molecular dioxygen teaches us about open shells, closed shells, and double bonds



Subshell	No. e⁻	Filled
2s	2	T
2p	6	T
2s	2	T
2p	6	T

Subshell	No. e⁻	Filled
2s	2	T
2p	5	F
2s	2	T
2p	5	F

Every breath you take: dioxygen provides the chemical energy that fuels you

The chemical energy utilized by most complex multicellular organisms is not predominantly stored in glucose or fat, but rather in O_2 with its relatively weak double bond. Methane (i.e., in combustion) or fatty acids (i.e., in cellular respiration) are "energy-rich fuels" compared to, say, carbohydrates only because they unlock the energy of more O_2 molecules than other "fuels". And so, O_2, rather than glucose, NAD(P)H, or ATP, is the molecule that provides the most energy to animals and plants.

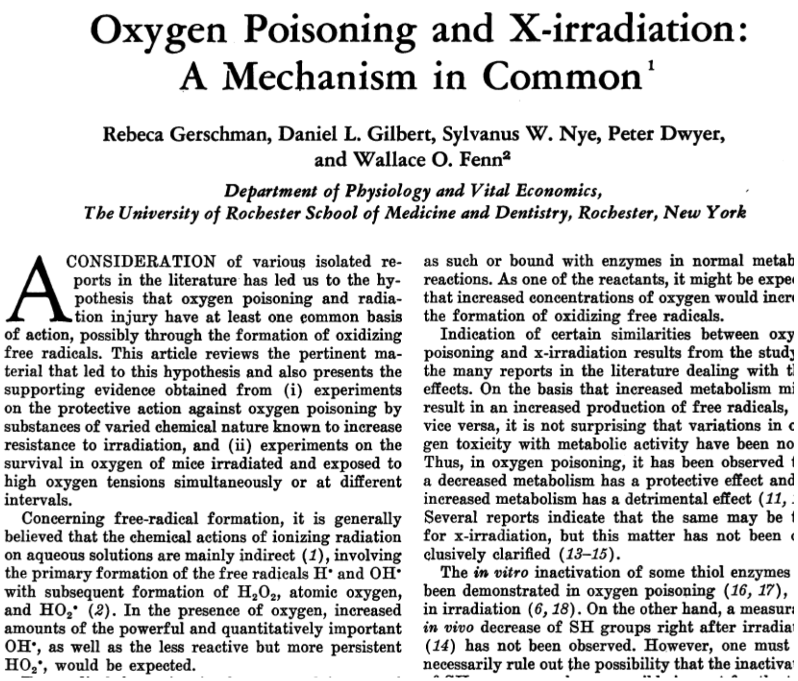
Oxygen (not proteins, carbohydrates, or fats) is the high-energy molecule that powers life.

Oxygen—A Critical, but Overlooke Nutrient

Paul Trayhurn [1,2*]

The Jekyll and Hyde of dioxygen

Science 07 May 1954: Vol. 119, Issue 3097, pp. 623-626
DOI: 10.1126/science.119.3097.623



Oxygen Poisoning and X-irradiation: A Mechanism in Common[1]

Rebeca Gerschman, Daniel L. Gilbert, Sylvanus W. Nye, Peter Dwyer, and Wallace O. Fenn[2]

Department of Physiology and Vital Economics, The University of Rochester School of Medicine and Dentistry, Rochester, New York

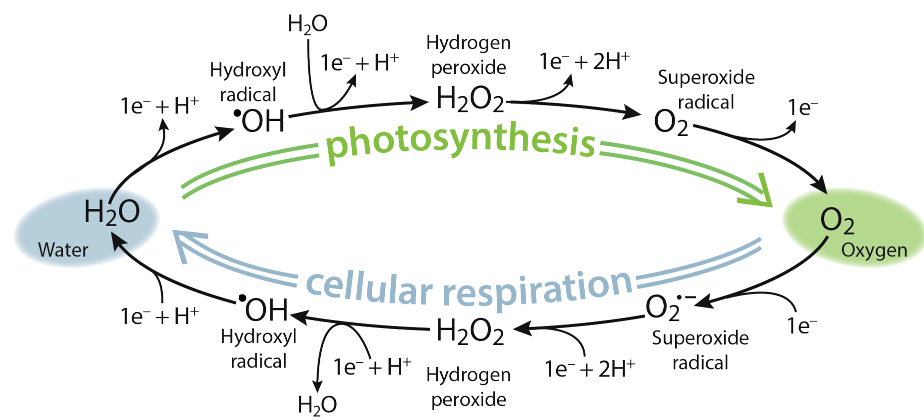
A CONSIDERATION of various isolated reports in the literature has led us to the hypothesis that oxygen poisoning and radiation injury have at least one common basis of action, possibly through the formation of oxidizing free radicals. This article reviews the pertinent material that led to this hypothesis and also presents the supporting evidence obtained from (i) experiments on the protective action against oxygen poisoning by substances of varied chemical nature known to increase resistance to irradiation, and (ii) experiments on the survival in oxygen of mice irradiated and exposed to high oxygen tensions simultaneously or at different intervals.

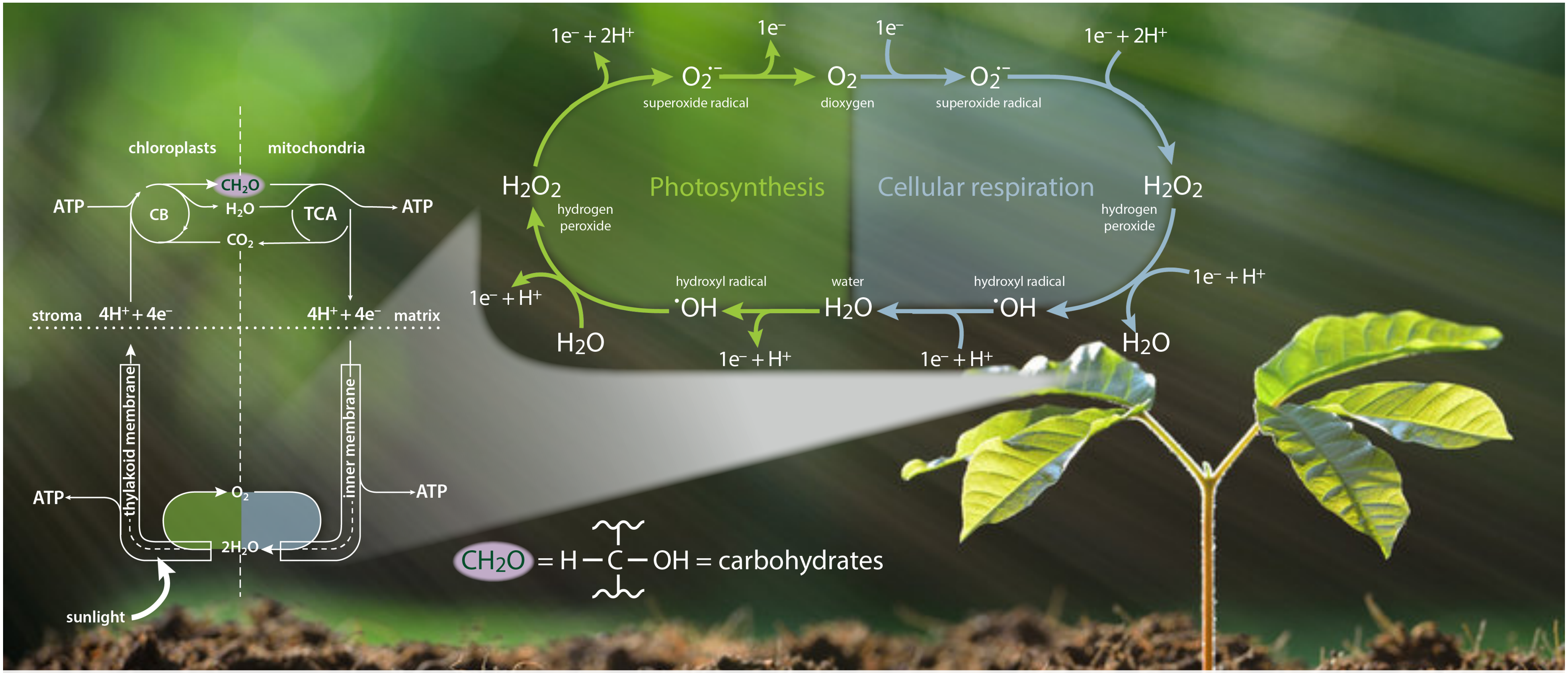
Concerning free-radical formation, it is generally believed that the chemical actions of ionizing radiation on aqueous solutions are mainly indirect (*1*), involving the primary formation of the free radicals H• and OH• with subsequent formation of H_2O_2, atomic oxygen, and HO_2• (*2*). In the presence of oxygen, increased amounts of the powerful and quantitatively important OH•, as well as the less reactive but more persistent HO_2•, would be expected.

as such or bound with enzymes in normal metab reactions. As one of the reactants, it might be expe that increased concentrations of oxygen would incr the formation of oxidizing free radicals.

Indication of certain similarities between oxy poisoning and x-irradiation results from the stud the many reports in the literature dealing with t effects. On the basis that increased metabolism mi result in an increased production of free radicals, vice versa, it is not surprising that variations in gen toxicity with metabolic activity have been no Thus, in oxygen poisoning, it has been observed a decreased metabolism has a protective effect and increased metabolism has a detrimental effect (*11*, Several reports indicate that the same may be for x-irradiation, but this matter has not been clusively clarified (*13–15*).

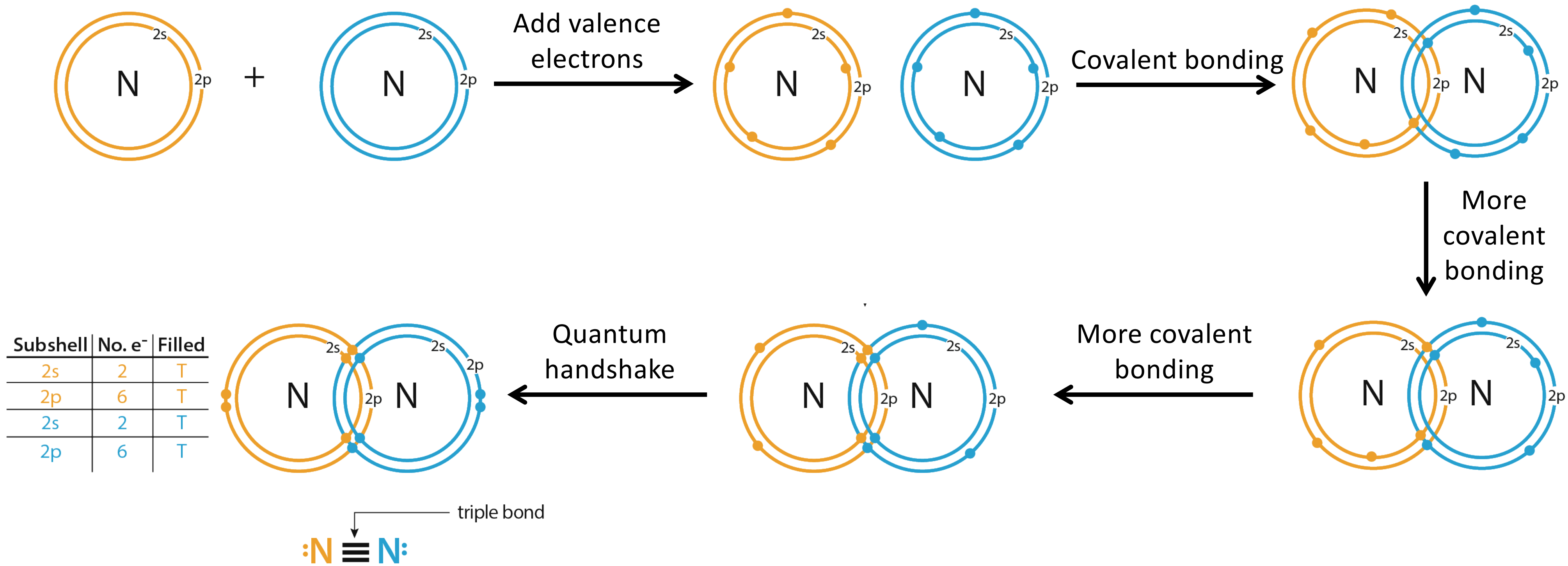
The *in vitro* inactivation of some thiol enzymes been demonstrated in oxygen poisoning (*16, 17*), in irradiation (*6, 18*). On the other hand, a measur *in vivo* decrease of SH groups right after irradia (*14*) has not been observed. However, one must necessarily rule out the possibility that the inactiva





Life's chemical symbiosis

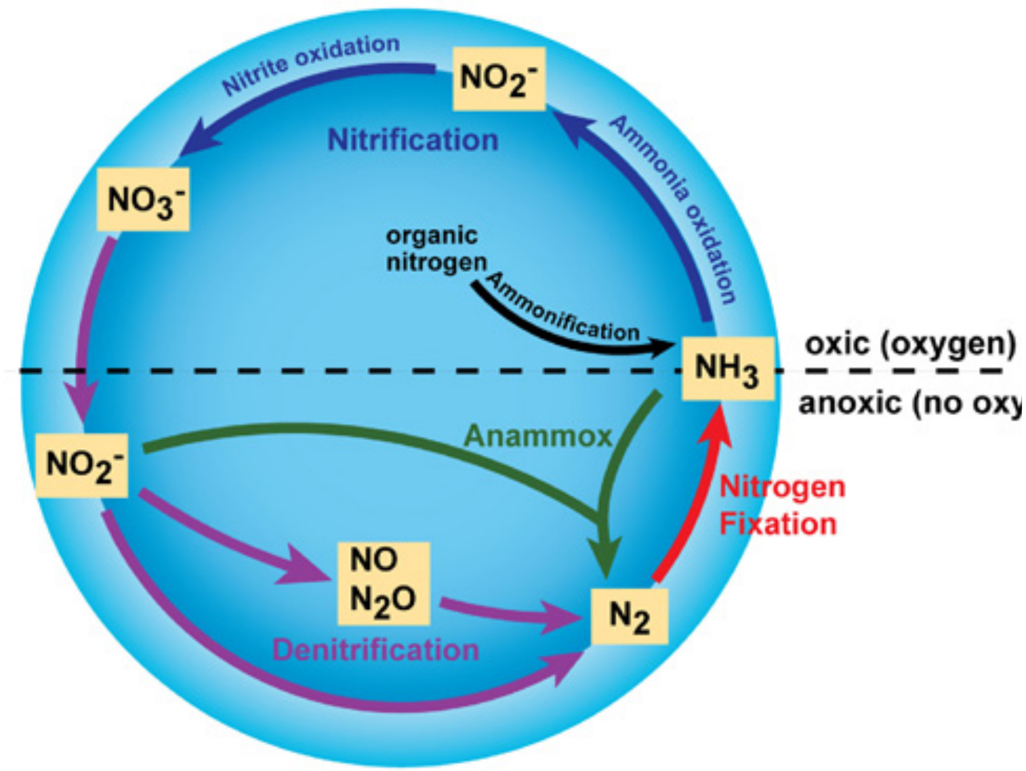
Dinitrogen and the triple bond



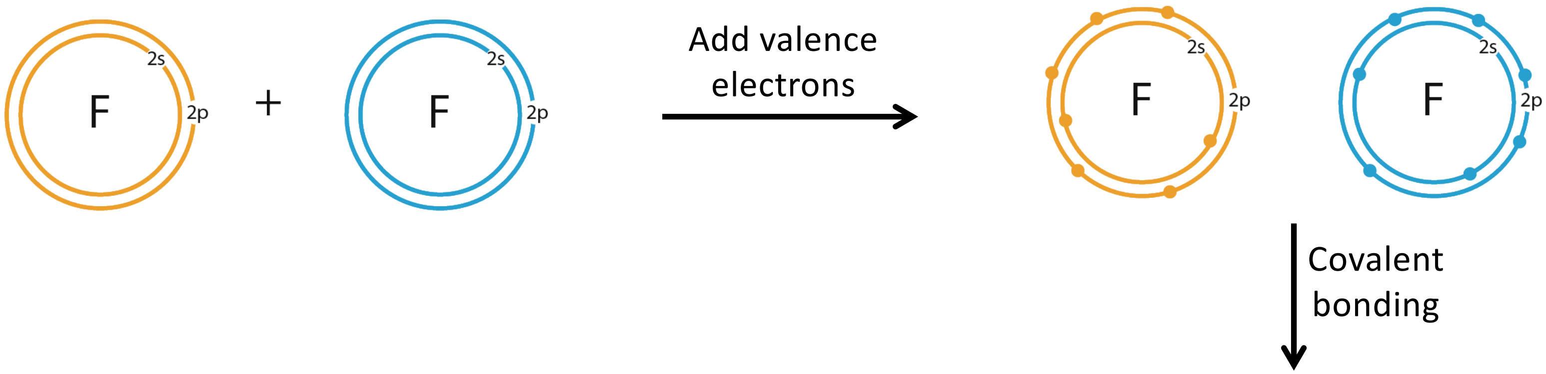
Subshell	No. e⁻	Filled
2s	2	T
2p	6	T
2s	2	T
2p	6	T

The dinitrogen molecule

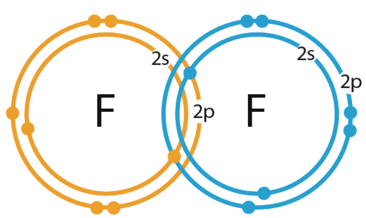
Nitrogen fixation



Molecular difluorine



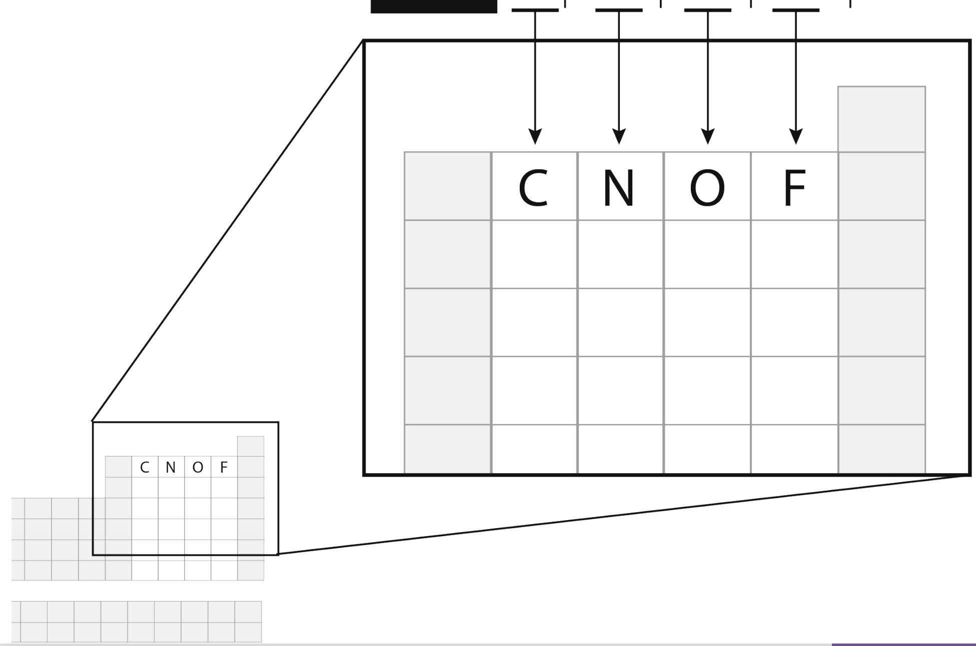
Subshell	No. e⁻	Filled
2s	2	T
2p	6	T
2s	2	T
2p	6	T



Pattern seekers

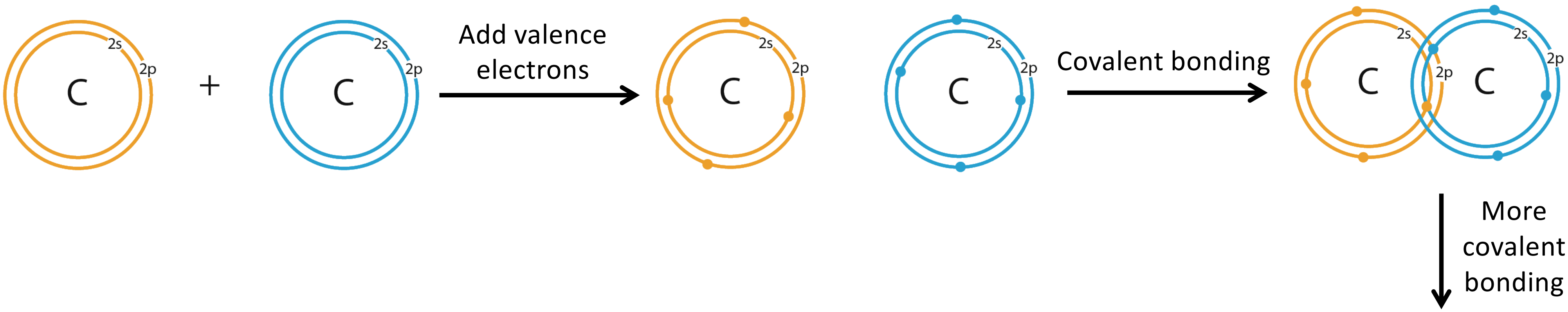
Given our results, deduce the patterns for bonding across the periodic table. Use this observation to write a hypothesis about dicarbon. Write your hypothesis as a factual statement. Name your hypothesis. Now test your hypothesis.

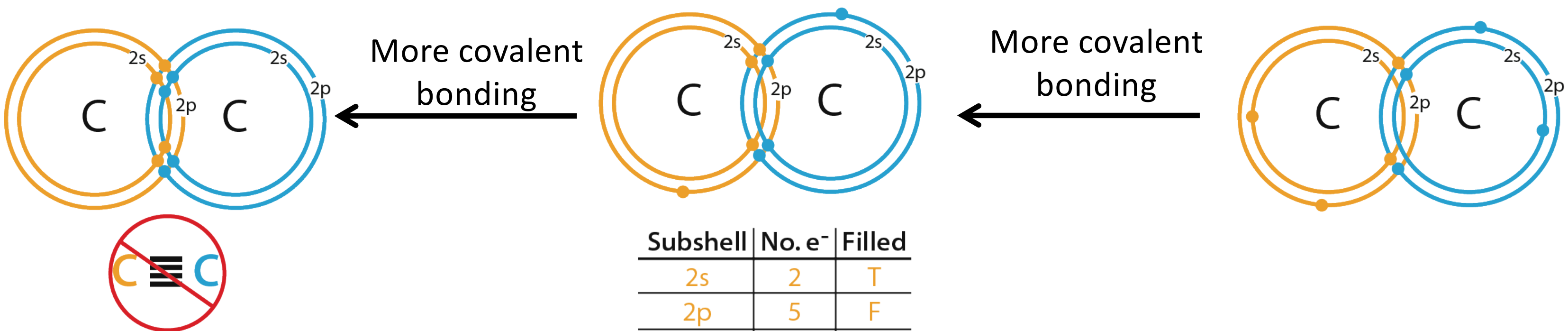
bond type	?	triple bond	double bond	single bond
no. lone pairs per atom	?	1	2	3
molecular structure	?	:N≡N:	$\ddot{O}=\ddot{O}$	:F̤̈–F̤̈:
diatomic molecule	C_2	N_2	O_2	F_2



Diatomic carbon breaks the pattern

(quadruple bonding is not possible with 2nd row elements)



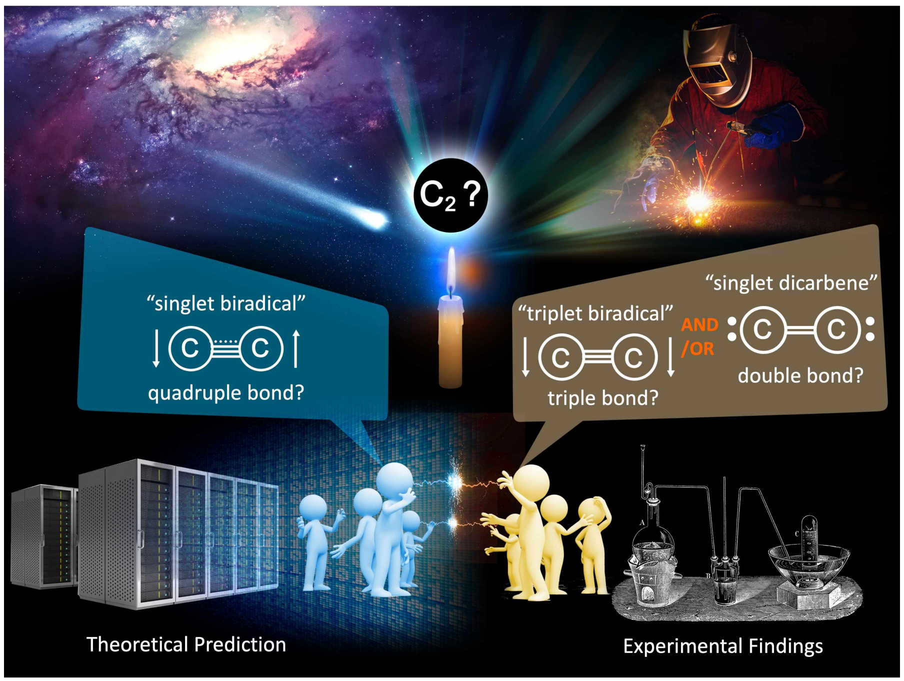


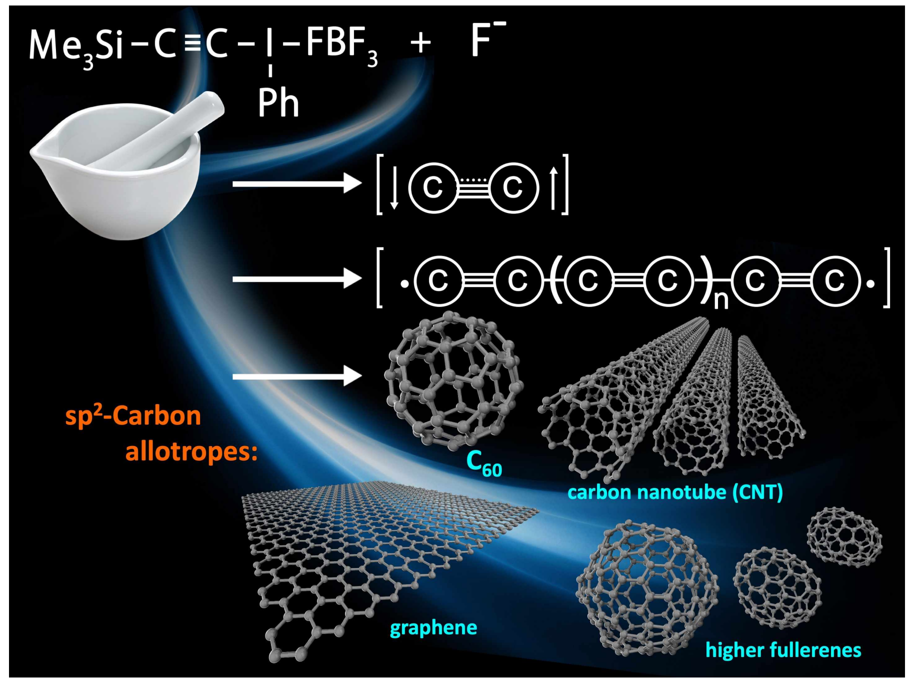
Subshell	No. e⁻	Filled
2s	4	F
2p	4	F
2s	4	F
2p	4	F

Subshell	No. e⁻	Filled
2s	2	T
2p	5	F
2s	2	T
2p	5	F

Room-temperature chemical synthesis of C_2 and role in nanocarbon formation

Nature Communications **volume 11**, Article number: 2134 (2020)





Electron Pair Domain	Number of Bonding Pairs	Representation	Total Electron Count
nonbonding domain	0	$\ddot{A}$	2
single bond domain	1	A—A	2
double bond domain	2	A=A	4
triple bond domain	3	A≡A	6

Electron pair domains (EPDs)

Regions around an atom having a high density of valence-shell electrons are called electron pair domains. An **electron-pair domain** consists of either a nonbonding pair of electrons, a single pair of bonding electrons, two pairs of bonding electrons, or three pairs of bonding electrons. A single pair of bonding electrons is known as a single bond; two or more pairs of bonding electrons are called multiple bonds.

Charge of the whole molecule

Molecules are neutral, cationic, or anionic according to their overall state of charge. Here's a look at how molecular charge is calculated for ammonia.