Singapore Chemistry League 2023

Catalytic Craze Problems and Solutions

Problem Setters

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CC1: The Circle (or Pentagon?) Of Life

The ancient Chinese (and some modern ones) believed in the importance of the *Wuxing* (Five Agents), which comprised Wood, Fire, Earth, Metal and Water. Complex interactions between these agents were said to explain everyday phenomena, with things like colours, music notes, smells and martial arts being assigned classes according to these agents.

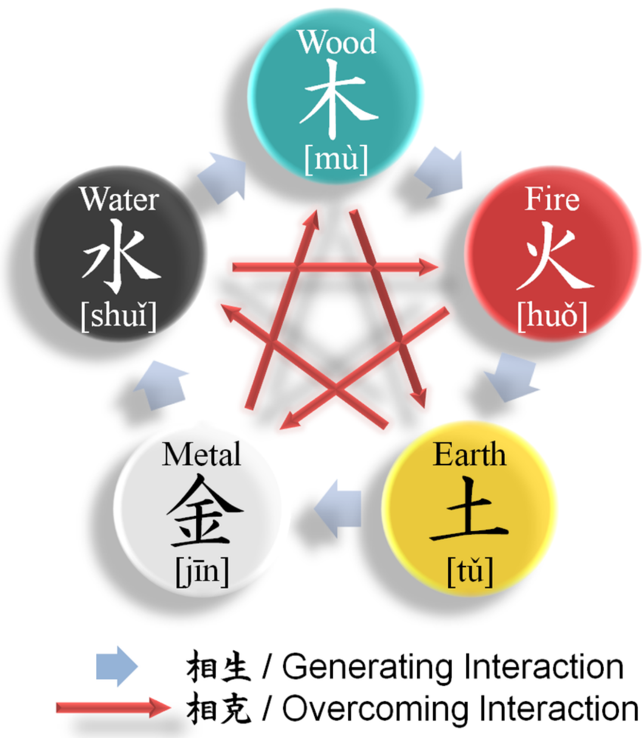


Figure 1: The true Spiral Periodic Table

From this point onwards, all mythology has been conceived by the author.
For any calculations for this question, please use molar masses ***rounded to the nearest whole number*** *(e.g. the molar mass of hydrogen is 1.)*

Chinese alchemists (and the author) also joined in the fun and assigned the *Wuxing* to chemical substances. Your job is to refer to the ancient Chinese texts, uncovered by a helpful archaeologist, and deduce the relevant compounds for each agent.

The Scroll of Wood

This scroll sheds light on the very first substance.

This binary compound is 63.33% the heavier element by mass.

This substance is a relative of a common class of reagent in organic chemistry which can typically add or insert.

Archaeologist's annotation: I wish I had one.

The Scroll of Fire

This scroll comes with a warning to not try this at home.

This organic compound allows us to control fire. A common mixture that contains this compound is poured into a bowl, then lit on fire. If one quickly picks up a bit of the mixture, one can hold fire in his hands without being burnt or hurt.

Perhaps this mixture has some "fire" innate in it, since it is commonly used to kill "enemies" which pollute the land with 99.99% effectiveness (what a nice number! Almost as if it's a marketing gimmick in a commonly encountered product…).

Within the mixture we find many brothers. Some are heavier, some are lighter. We desire one of the compounds that shares his weight with 2 other brothers, in both 2 and 3 dimensions.

Archaeologist's annotation: Interesting that that last number is divisible by 3. I wonder what else this number represents?

Also, there seems to be a typo in this scroll.

The Scroll of Earth

This scroll was buried deep in the ground.

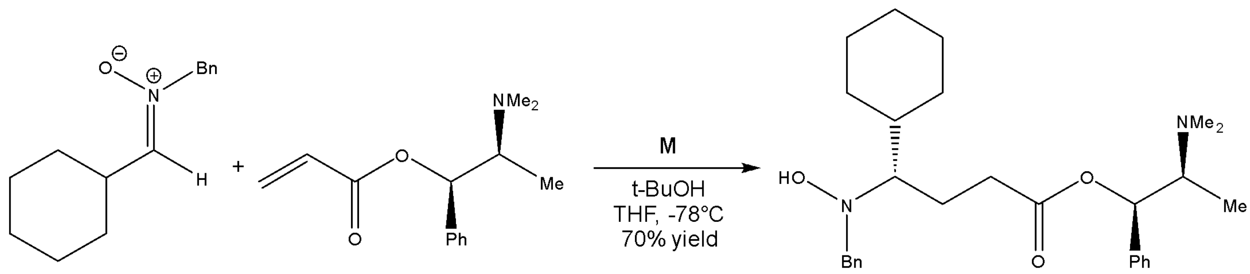
This compound is born of those who work the earth, and in turn gives life to others. It has 2 pKa's equal to 3.794 and 14.637. Heating this compound in acidified potassium permanganate gives an alpha-keto acid. This compound gives a yellow precipitate when heated with aqueous alkaline iodine.

Archaeologist's annotation: What a waste.

The Scroll of Metal

This scroll presented a radical idea.

This metal is useful in organic reactions. For instance, consider a compound **M** of this metal. **M** is useful in certain organic redox reactions. **M** is also often used to join carbons, such as in the following reaction.



M is 62.87% the heavier element by mass.

Archaeologist's annotation: This has reminded me that I need to cut my hair. Best to get it from the most successful one…

The Scroll of Water

This scroll has nothing to do with water. The author is out of ideas.

This compound, **A**, is not very soluble in water.

1H NMR spectrum of **A**: δ 1.02 (3H, t, J = 7.5 Hz), 2.43 (3H, s), 2.68 (2H, q, J = 7.5 Hz), 6.98 (1H, ddd, J = 7.9, 2.0, 1.5 Hz), 7.09-7.57 (5H, 7.15 (ddd, J = 2.7, 2.0, 0.5 Hz), 7.17 (ddd, J = 8.1, 2.7, 1.5 Hz), 7.25 (ddd, J = 8.1, 7.9, 0.5 Hz), 7.38 (ddd, J = 7.9, 1.3, 1.1 Hz), 7.50 (ddd, J = 8.5, 7.9, 0.4 Hz)), 7.83-8.02 (2H, 7.89 (ddd, J = 8.5, 1.5, 1.1 Hz), 7.96 (ddd, J = 1.5, 1.3, 0.4 Hz)). Labile protons appear in the NMR.

Archaeologist's annotation: Is this really important?

Finally, the archaeologist finds one last scroll.

The Scroll of Quintessence

This scroll is the final answer to life, the universe and everything.

There is a sixth substance which holds the entire universe together.

The journey to the quintessence may be heavy, but follows the progression of nature.

Sunflowers, nautilus shells, hurricanes - find the rhythm of the universe hidden within.

Its backbone comes from something tasting sour, but a bit less hydrated.

Indeed, brothers have gone opposite ways looking for this, never to be together again.

And something familiar shields it three times, bonded as reliably as quartz crystals are

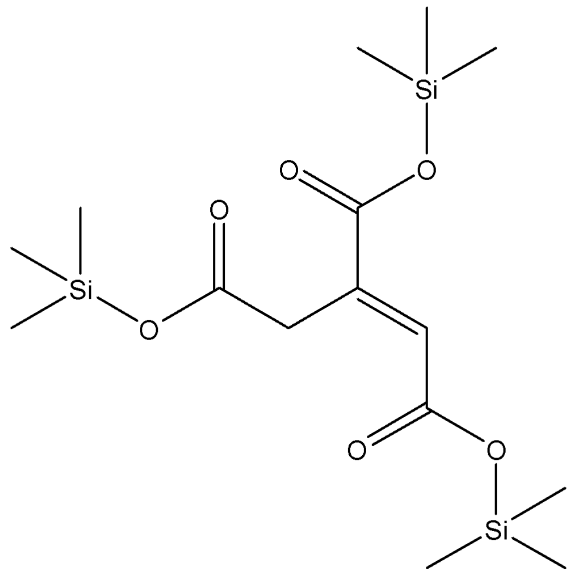
Archaeologist's annotation: A cone it... sounds familiar?

Give the structure of the substance which represents the Quintessence.

Hint: The Quintessence, as suggested in the scroll, follows in a logical and natural progression from the previous five substances.

Solution:

The quintessence has the following structure:



Solving the scrolls in order:

Wood

The 63.33% does look rather suspicious, doesn't it? What a nice number. If you try different multiples of 3 for the relative molecular mass (remember, use 0d.p!), and in conjunction with the formula being **XY**, you will eventually reach boron monofluoride (BF), which the archaeologist clearly wishes they had. BF is also a borylene, a relative of carbenes.

Fire

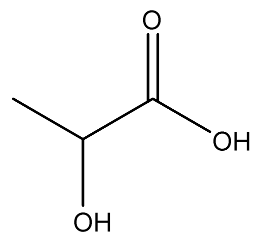
This is a common party trick (but don't try this without supervision!) If you search the internet, you can find videos of people holding fire without being burnt using hand sanitizer (which is often claimed to kill germs on one's hand, not land - that's the typo!, with 99.99% effectiveness). What is the key compound in hand sanitiser but alcohol?

It may be slightly trickier to determine the alcohol in question, but this is where the last part comes in handy. What could "the compound that shares his weight with 2 other brothers, in both 2 and 3 dimensions" mean? The weight, of course, refers to the molecule mass of the compound. Thus, we are looking at a group of alcohols with the same molecular mass. The "2 other brothers" suggest that it has exactly 2 other isomers, both when we exclude and include stereochemistry (thus in 2 and 3 dimensions, respectively). The only alcohol that fulfils this criteria, and is also found in disinfectant, is C_3H_8O.

In addition, the archaeologist gave us a useful hint about the number 3. Out of the common alcohols used in sanitisers (isopropanol, ethanol, or propan-1-ol), the answer must be either isopropanol or propan-1-ol as they have 3 carbons. But which one is it? We might have to leave a question mark here first.

Earth

This is quite a simple one to find. The pKa's tell us that there is a carboxylic acid and an alcohol in the compound. The alpha-keto acid must come from an alcohol that was adjacent to a carboxylic acid. All that remains is to find what is bonded to the alcohol carbon. The iodoform test tells us it must be a methyl group. The compound in question is lactic acid.



lactic acid

Metal

We can try out different methods of attacking the question. You may know that samarium(II) iodide is often used as a reducing agent and to facilitate carbon-carbon coupling.

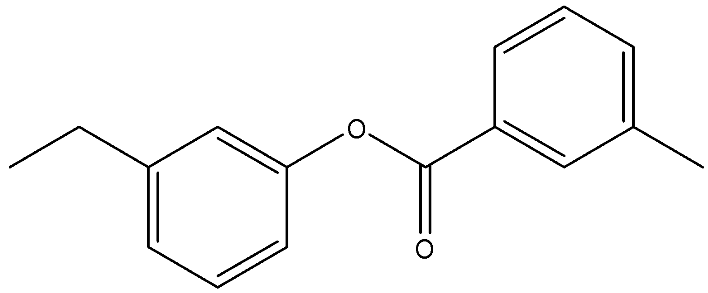
Or you may have guessed this from the Barbier (barber) and Pinacol (pinnacle) reactions hinted to in the annotations. If you didn't, you have no choice but to try out different values of masses until you obtain that the metal we are looking for is samarium.

Water

This question initially looks like a toughie since we need to reconstruct the molecule from scratch. However, the exact structure of the compound is actually not needed for this question, only the formula is.

Let's look at the NMR: we have a methyl group (3H) and an ethyl group (2H + 3H). We then have a series of hydrogens with chemical shift close to 7 (aromatic ring). In total, we have 1H + 5H + 2H = 8H on aromatic rings. If we assume 2 benzene rings, we have 12 slots that need to be filled, of which 10 are accounted for (8 hydrogens and 2 additional groups). Initially, it may be tempting to just join the two benzene rings directly, but then **A** would not be hydrolysed by acid. Instead, various clues (the relatively higher shift of 2 protons adjacent to a C=O as well as the clue about the hydrolysis products) indicate that an ester is present which joins the two rings. This gives us a formula of $C_{16}H_{16}O_2$.

If you did try and piece together the whole molecule, good job! You can check your answer below.



Quintessence

To begin working on the quintessence, we need to reconsider our previous answers.

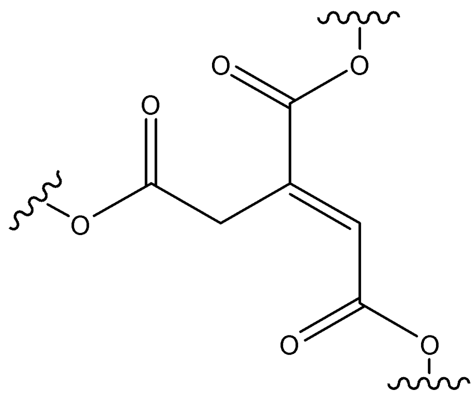
Wood: boron monofluoride
Fire: isopropanol or propan-1-ol
Earth: lactic acid
Metal: samarium
Water: $C_{16}H_{16}O_2$

It doesn't seem like there is a natural relationship or sequence between these five things, so maybe the relation lies somewhere else. Recall the (rather odd) instruction at the start to only consider masses to the nearest whole number. Maybe that comes into play here? Try calculating all the molar masses of the answers.

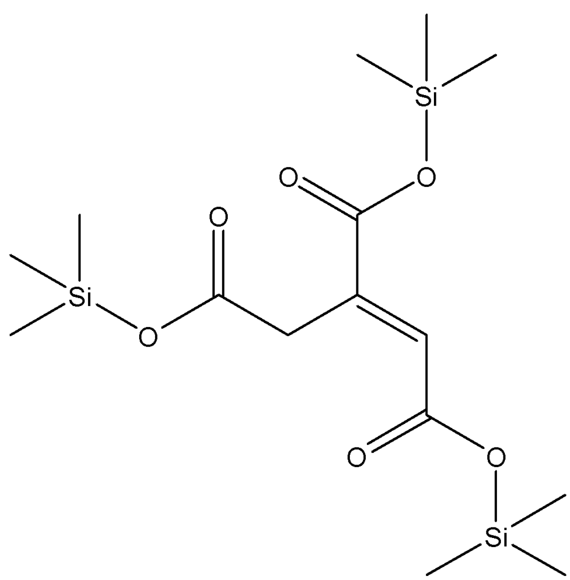
Wood: boron monofluoride (30)
Fire: isopropanol or propan-1-ol (60)
Earth: lactic acid (90)
Metal: samarium (150)
Water: $C_{16}H_{16}O_2$ (240)

This is useful to us: if you can spot it, the pattern is that the molar mass of each item is the sum of the previous two molar masses (a Fibonacci-ish pattern). It follows that the molar mass of our final answer must be 390 g mol^{-1}, our first big clue.

What compound is this exactly? We can look at the scroll for a hint – what is sour? Well, most sour flavours come from citric acid. But the scroll says it is a bit less hydrated – literally speaking, perhaps dehydrated? If citric acid is dehydrated, we obtain aconitic acid (which matches the annotation). But is it trans or cis? Well, if brothers have gone <u>opposite</u> ways, we must be looking for the trans E isomer, since E comes from *entgegen* - German for opposite. Them being never <u>together</u> again is a reference to *zusammen*, which is German for together. This gives us the following skeleton.



What is the remaining part bonded to each end? Well, the skeleton we have has a molar mass of 171 g mol^{-1}, which leaves 73 g mol^{-1} for each end. If you do some trying around (with protecting groups given in the hint), you will find that this matches quite nicely with a trimethylsilyl (TMS) group. Indeed, the answer we are looking for has a TMS group bonded to each oxygen, as shown again below.



CC2: The Twenty Rooms

You and your teammates find yourselves in a dungeon. You have no recollection of why and how you ended up in it, or who your captors are.

The dungeon, as you discover, is a large underground chamber with twenty rooms. On the door of every room is a rusty iron plaque, each etched with a different number.

Your teammate finds a slip of paper on the ground nearby. Opening it up, it reads:

> Each room has a (chemistry-related) clue that will point you to a specific number. Go to the room marked with that number next and continue solving its clue. You must visit each room once and only once. The locked exit door is found in room 363 - its passcode will be the room numbers of the 5th, 10th and 18th room you visit in this journey, written together as one number.

Following it is a short phrase:

> "**A period at the very end of the sentence.**"

You and your teammates decide that this seemingly out-of-place line could be an important hint at the starting room. The element at the very end of the very last period of the periodic table is Oganesson, at element number 118. Seeing as there is a room labelled "**118**", you decide to start your journey from there and strike it out from the list of room numbers you have made.

*Begin your dungeon crawl from **Room 118** and work through the rest of the rooms, ending at **Room 363**. Good luck!*

Find the 5th, 10th and 18th rooms you visit in this journey. Key in your answer as a concatenated number from left to right. For example, if you believe the 3 rooms are **Room 57**, **Room 1876** and **Room 9** respectively, key in your answer as **5718769**.

Room 2

You find a slip of paper which reads,

"**O your majesty $C_{10}H_{20}O_5$, has dropped your ____.**
Oh my! What would be left of my name without it?"

Room 5

You enter the room and prepare yourself for a drawing exercise.

"**Of all the stable, isolable structural isomers of C_4H_8O and ignoring stereoisomers, there are in total *a* ethers, *b* epoxides, *c* (non-epoxide) compounds which react with dry HCl under heat, and *d* compounds which give a reddish-brown precipitate with Fehling's solution. Find the numerical value of $(a \times b) + (c \times d)$.**"

Room 9

You find a slip of paper which reads,

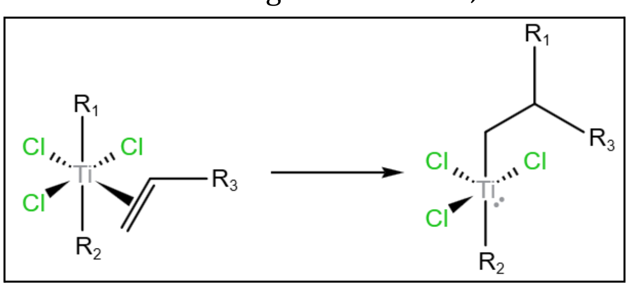
"**He discovered the New World. He was to be honoured in the periodic table, but his name was not preserved. Instead, the daughter of a tormented Greek was preferred."**

Room 12

You push open the door but it slams into the corner of a long, varnished, antique-looking wooden table, causing it only to open halfway. **On the table, you find an experimental setup of a bygone age, consisting of a grey stone next to an object with a radiation warning labelled on it. You notice the inscriptions "up, down, down" on the stone with the markings of a certain year that has been eroded - 19__.**

Room 20

You see a note with the following reaction on it, with the number:



Nobel Prize of 19___

Room 25

You find a slip of paper which reads,

?
______ , green, blue, yellow

Some numbers and words seem to be missing…

Room 32

In this room you find a word ladder of element names, written in the form of a poem - a word ladder is a puzzle with a sequence of words, where adjacent words differ from each other by a single letter.

"**This hefty solid is nothing new; let**
Us spell out its full name and begin the swaps.
Change one letter and rearrange to get
An element with the rarest pink salts.

Shed one letter and replace with a "c",
Its namesake is a natural satellite.
Swap out one letter and leave the rest be,
You'd rest your gaze upon a nobel sight.

Replace one, switch around and you will find
One element's name that's been lost to time."

What is the atomic number of the element at the start of this word ladder?

Room 41

You find a slip of paper which reads,

"**The elements in each set have something in common with each other - this common point is related to a specific whole number.**

(a) F, Cl, Br, I — connected by x
(b) Cr, Mn, Mo, Tc — connected by y
(c) Ne, Kr, Xe, Po — connected by z

What is the numerical value of $z - (x + y)$?"

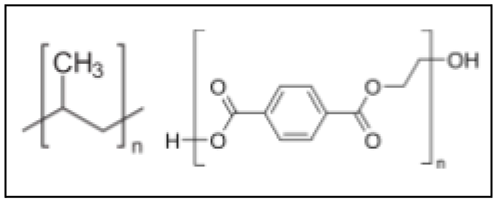
Room 51

You find a slip of paper which reads,

"**I am named after a quality of a plant. I've served humanity before, much to its dismay. As a result, people have come to associate me with Prussian blue and perhaps Thanatos. What am I?**"

Room 56

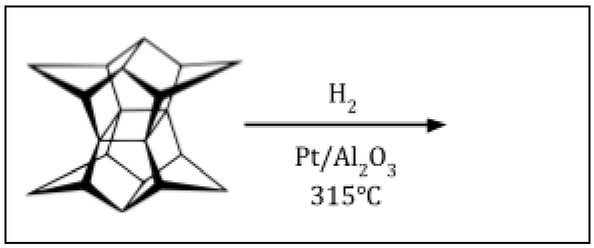
You see the image



What number may their resin identification codes give?

Room 57

You see the reaction



Room 60

Opening the door, you hear a loud, low hum coming from the adjacent room. On the wall of the room you see the equation

$$P_4S_3 \xrightarrow[\text{heat}]{\text{Excess S}} P_4S_m$$

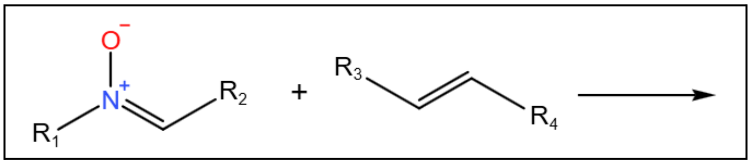
Room 63

You open the door to find a fume hood (really? In a dungeon? Was that where the noise was coming from?) with a beaker of unknown colourless liquid inside it. A note next to the beaker reads,

"**This inorganic chemical has many similarities to its multifaceted cousin, '66'. They both possess a certain chemical property which we are more commonly accustomed to see in an organic context. Splitting its common name in half, the first part of its name shares an inexplicable similarity to a symbol characteristic to '66'... Even though that was not what it was named after. '66' is to this chemical's cousin as __ is to this chemical.**"

Room 70

You hear the same whirring noise coming from the adjacent room. Then, you see the reaction



Are we about to do maths?

Room 81

You see a sealed bottle of unknown liquid. Its label writes:

"**Chemists use it often, as do criminals. It is both solvent and sedative. It is notoriously misunderstood by popular culture - its action is slower than expected. Leave it out in the air and you get a dangerous chemical weapon. Its danger has made it R-rated. Add a powerful base and you have a cyclopropanating agent. It is marketed as a Freon - but which one?**

Room 118

You find a slip of paper which reads,

"**The weight of Uncle Roger's favourite condiment.**"

Wasn't he the guy who made egg fried rice?

Room 155

You find a slip of paper which reads,

"**The youngest of four siblings, all born in the same Swedish village.**"

Room 169

You find a slip of paper with the letters "**purzvfgf sbbgonyy**". The back side of the paper says "**If you are lost, let a famous Roman general decipher your confusion.**".

Room 363

Only one thing stands between you and your team's freedom behind this door - the correct passcode!

Room 1876

You find a slip of paper with a grid on it, containing letters which you recognise as the Japanese Hiragana alphabet. Under each alphabet is the sound it makes when spoken, commonly referred to as romaji. (next page)

Hiragana				
あ a	い i	う u	え e	お o
か ka	き ki	く ku	け ke	こ ko
が ga	ぎ gi	ぐ gu	げ ge	ご go
さ sa	し shi	す su	せ se	そ so
ざ za	じ ji	ず zu	ぜ ze	ぞ zo
た ta	ち chi	つ tsu	て te	と to
だ da	ぢ ji	づ zu	で de	ど do
な na	に ni	ぬ nu	ね ne	の no
は ha	ひ hi	ふ fu	へ he	ほ ho
ば ba	び bi	ぶ bu	べ be	ぼ bo
ぱ pa	ぴ pi	ぷ pu	ぺ pe	ぽ po
ま ma	み mi	む mu	め me	も mo
や ya		ゆ yu		よ yo
ら ra	り ri	る ru	れ re	ろ ro
わ wa				を wo
ん n				

On the flip side of the paper you find the prompt leading to the next room:
"**How many Japanese alphabets from the grid, when in romaji, appear as atomic symbols in the periodic table?**"

Solution:

417020

The rooms in order:
118 → 169 → 60 → 9 → 41 → 1876 → 25 → 2 → 155 → 70 → 5 → 57 → 12 → 32 → 56 → 51 → 81 → 20 → 63 → 363

#1: Room 118

You find a slip of paper which reads,
*"**The weight of Uncle Roger's favourite condiment.**"*
Wasn't he the guy who made egg fried rice?

Many of you may remember Uncle Roger as the cheeky, audacious character created by online personality and comedian Nigel Ng. Always clad in an orange shirt, he has made a name for himself by reviewing food videos, particularly on fried rice. One of his favourite ingredients that he features is **MSG** (monosodium glutamate), a salt of the amino acid called glutamic acid. The "weight" of MSG, otherwise its molar mass, is 169.11 $gmol^{-1}$ (for anhydrous MSG). Rounding to 3 s.f., it is 169.

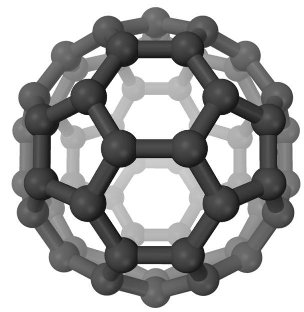
We go to room **169**.

#2: Room 169

*You find a slip of paper with the letters "**purzvfgf sbbgonyy**". The back side of the paper says "**If you are lost, let a famous Roman general decipher your confusion.**".*

The clue of a Roman general at the flip side of the slip most likely hints that the message is encoded through a **Caesar cipher** which replaces every letter with another that is "shifted" a certain number of spaces away from it. By using an online Caesar cipher decryption tool or testing cases, we find that the message can be decoded to "chemists football" when the shift is 13. This uses a specific case in the Caesar cipher known as the ROT 13 cipher, which means every letter is replaced by another which is 13 letters away from it. In this case "a" becomes "n", "b" becomes "o", and so on.

We are left with the message "**chemists' football**". Perhaps one of the few "footballs" of the greatest relevance in chemistry is the carbon molecule buckminsterfullerene - an unusual spherical molecule with arrangements of pentagonal and hexagonal shaped rings very much like the patterns on a football. Even more unusually, the compound has a colour! The molecule produces a violet colour when dissolved in organic solvents.



Fullerenes are an allotrope of carbon: they are composed of only carbon atoms, connected by single and double bonds, to form structures like spheres, ellipsoids or tubes. Buckminsterfullerene is the most common fullerene with the chemical formula C_{60}. In academia, C_{60} is the most common way of referring to this molecule, and seeing as there is a room **60**, this does appear to be the likeliest option.

#3: Room 60

Opening the door, you hear a loud, low hum coming from a room beside. On the wall of the room you see the equation

$$P_4S_3 \xrightarrow[\text{heat}]{\text{Excess S}} P_4S_{\mathbf{m}}$$

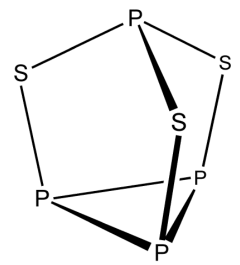
Fortunately or not, there are no gimmicks in this room. The clue is an inorganic reaction, and the value of **m** is presumably the number that leads to the next room.

As a preliminary problem-solving step it is possible to narrow our options for **m**. Recall that the unique number which the clues of each room point to has to have a corresponding room numbered with it, and therefore the answer cannot be 6 or 7, because there is no room 6 or room 7. Conversely, with this in mind, it is possible (and strategic!) to make some guesses on what **m** could be based on the rooms there are.

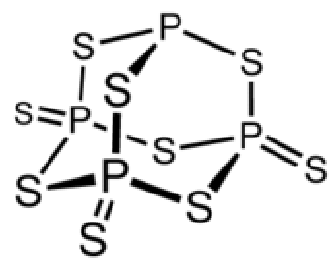
The reaction is expected to increase the number of S atoms in the reactant P_4S_3 because it is being reacted with more sulfur. This rules out room 2. On the other hand, the value of **m** is not expected to be extremely large. The number of S atoms should not become significantly greater than that of P atoms, and so 5, 9 or 12 are the more possible values for **m**.

To find its exact value may be more tricky, but it can be done with a bit of inorganic reaction knowledge. The reaction of P_4S_3 (sulfur sesquisulfide) in excess sulfur produces $\mathbf{P_4S_9}$.

For interest, the unique structures of the two molecules are shown below. The chemistry of main group elements can occur in unusual ways, forming 3-dimensional arrangements akin to the ones common in organic molecules.



P_4S_3



P_4S_9

The value of **m** is 9, and we head to room **9**.

#4: Room 9

You find a slip of paper which reads,

"He discovered the New World. He was to be honoured in the periodic table, but his name was not preserved. Instead, the daughter of a tormented Greek was preferred."

The mention of the discoverer of "the New World" brings to mind Explorer **Christopher Columbus**, who discovered the Americas in 1492. The line "He was to be honoured in the periodic table, but his name was not preserved" suggests a chemical, compound or element which was initially to be named after him but now no longer so. In addition, this chemical element has been named after "the daughter of a tormented Greek" instead.

It takes a hefty grasp of trivia to find that the chemical element **niobium**, at atomic number **41**, originally had atomic symbol Cb and was named "columbium" - named after the personified name of the United States, Columbia (think movie company, or the US state), in turn named in honour of Columbus. Its current name comes from "Niobe", who was the daughter of Tantalus, who was tormented by being made to stand in a pool of water and with a fruit tree hanging over him. The water recedes when he attempts to drink from it, and the fruit tree retracts when he attempts to pluck its fruits.

#5: Room 41

You find a slip of paper which reads,

*"**The elements in each set have something in common with each other - this common point is related to a specific whole number.***
(a) F, Cl, Br, I — connected by x
(b) Cr, Mn, Mo, Tc — connected by y
(c) Ne, Kr, Xe, Po — connected by z
What is the numerical value of z — (x + y)?"

Part (a) should not be foreign as fluorine, chlorine, bromine and iodine are all halogens, belonging to **Group 17** of the periodic table. Early conventions may place the halogens into Group VII, with Roman numeral 7, but in most educational contexts, the common practice is to refer to them as Group 17 elements. Hence x is 17.

Part (b) is trickier; one of the clearer similarities between chromium, manganese, molybdenum and technetium is that they are all transition metals. With some observation, we note that these 4 elements occupy the central portion of the d-block of the periodic table. This may lead us to notice that these elements have metal atoms with a **d^5 electron configuration** in their ground states. Indeed, the electron configuration of chromium, $[Ar]3d^5 4s^1$, is frequently taught as an anomaly owing to the low energy gap between the 4s and 3d subshells, which facilitates the promotion of an electron from the 4s to the 3d subshell to reduce inter-electronic repulsion. A similar reasoning holds for molybdenum, with electron configuration $[Kr]4d^5 5s^1$. The equivalent d electron count for transition metal atoms in their ground state leads to certain similarities in their chemical properties, for example, the octahedral geometry of their metal complexes. We find that y is 5.

Part (c) may be the most problematic. It is tempting to group neon, krypton and xenon together as noble gases and hence assign them in Group 18, if not for the addition of polonium which feels frustratingly out of place. However, the solution is reached from a non-chemical perspective. After eliminating the possibilities for similar chemical and physical properties, we may examine the history behind each element and find that surprisingly, all four elements were **discovered in the same year, 1898**. Hence z is 1898.

We find $z - x - y = 1898 - 17 - 5 = \mathbf{1876}$.

#6: Room 1876

You find a slip of paper with a grid on it, containing letters which you recognise as the Japanese Hiragana alphabet. Under each alphabet is the sound it makes when spoken, commonly referred to as romaji.

Hiragana				
あ a	い i	う u	え e	お o
か ka	き ki	く ku	け ke	こ ko
が ga	ぎ gi	ぐ gu	げ ge	ご go
さ sa	し shi	す su	せ se	そ so
ざ za	じ ji	ず zu	ぜ ze	ぞ zo
た ta	ち chi	つ tsu	て te	と to
だ da	ぢ ji	づ zu	で de	ど do
な na	に ni	ぬ nu	ね ne	の no
は ha	ひ hi	ふ fu	へ he	ほ ho
ば ba	び bi	ぶ bu	べ be	ぼ bo
ぱ pa	ぴ pi	ぷ pu	ぺ pe	ぽ po
ま ma	み mi	む mu	め me	も mo
や ya		ゆ yu		よ yo
ら ra	り ri	る ru	れ re	ろ ro
わ wa				を wo
ん n				

On the flip side of the paper you find the prompt leading to the next room:
*"**How many Japanese alphabets from the grid, when in romaji, appear as atomic symbols in the periodic table?**"*

There are **25** romaji letters that appear as atomic symbols: i (iodine), u (uranium), o (oxygen), ga (gallium), ge (germanium), se (selenium), ta (tantalum), te (tellurium), na (sodium), ni (nickel), ne (neon), no (nobelium), he (helium), ho (holmium), ba (barium), bi (bismuth), be (beryllium), pa (protactinium), pu (plutonium), po (polonium), mo (molybdenum), ra (radium), ru (ruthenium), re (rhenium) and n (nitrogen). Teams may find it helpful to use the periodic table in a data sheet as a guide, ticking off elements as they go down the grid.

#7: Room 25

You find a slip of paper which reads,

?
______ , green, blue, yellow

At first sight, there is a colour that is missing from a given sequence of colours. However, as the answer has to be a numerical value, we can assume that the missing colour is associated with a certain specific number that we need to find.

Colour in a chemical context is niche and usually points to a few selected cases. These include the emission spectra of atoms, conjugated organic molecules, and transition metal complexes. Emission spectra identify and arrange colours according to increasing wavelengths, which is not the case in our clue. On the other hand for conjugated organic molecules, the number of transformations to its molecular structures which contribute to their colour change is usually limited, and unlikely to produce the wider variety of four different colours that our clue suggests. It is most likely that the clue is pointing to a sequence of colour changes produced by a transition metal ion.

By confirming this case, we can then make an educated guess that the sequence we have could be the colours produced by a solvated transition metal in different oxidation states. Which transition metal is able to produce green, blue and yellow solvated complexes?

We discover that **vanadium**, which exhibits variable oxidation states of +3, +4 and +5, has coloured hydrated complexes that are green, blue and yellow respectively, which fits our clue. Vanadium can also exist in the +2 oxidation state, forming a violet complex. If we were to fill in the missing spaces in the clue, it would look as follows:

Colours of hydrated vanadium ions of different oxidation states:

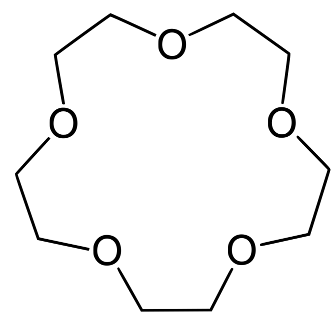
+2	***+3***	***+4***	***+5***
violet,	**green,**	**blue,**	**yellow**

As such, the missing number, as denoted by the question mark, is **2.**

#8: Room 2

You find a slip of paper which reads,
"O your majesty $C_{10}H_{20}O_5$, has dropped your ____.
Oh my! What would be left of my name without it?"

The answer to this riddle is **crown** - but in a chemistry context, it most likely refers to **crown ethers**, which are cyclic ethers with oxygen spaced at regular intervals. $C_{10}H_{20}O_5$ is conceivably the molecular formula of a crown ether with the common name **15-crown-5**. It is named as such due to its 5 oxygen atoms, and a total of 15 atoms forming the "studs" of the crown.



The answer which leads us to the next room comes from the numerical part of this common name, when we have removed the "crown" in the name, which is **155**.

#9: Room 155

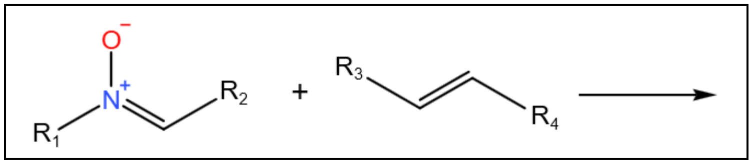
You find a slip of paper which reads,
*"**The youngest of four siblings, all born in the same Swedish village.**"*

In this riddle we are introduced to four related items that have the same namesake. Of which, we are to find the "youngest" of them, suggesting a chronological sequence that these items were formed, synthesized or discovered. While it is possible that these items are molecules or chemical structures, a better direction would be to consider the periodic table. Elements in the periodic table have known times of discovery, and the origins of their names are fairly unambiguous and unique.

Our "four siblings" are the four elements all named after the Swedish village of Ytterby: **yttrium, terbium, erbium and ytterbium**. The "youngest" of the elements, or the element with the most recent discovery date, is **ytterbium** which was first isolated in 1878. We can move on to room **70**, which is the atomic number of ytterbium.

#10: Room 70

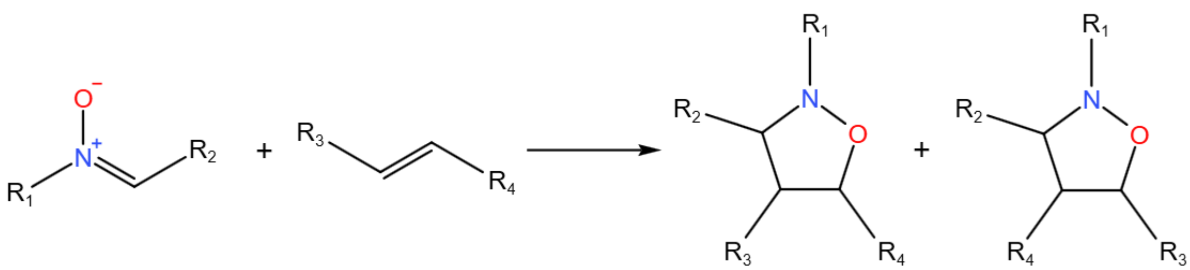
You hear the same whirring noise coming from the adjacent room. Then, you see the reaction



Are we about to do maths?

The use of a reaction scheme to embed a numerical clue is similar to the one we encountered in room 60, only this time the number to be found is less obvious.

The reaction is a type of 1,3-dipolar cycloaddition - 1,3-dipolar describes the dipole on the nitrone species on the left, which is spread over 3 atoms (the O, N and the C atom double bonded to N), while cycloaddition reveals that the final product of the reaction is a ring. Specifically, the reaction is called a **nitrone-olefin [3+2] cycloaddition**, and produces the final products:



This is an example of a [3+2] cycloaddition, meaning that it forms a 5-membered cyclic product without the loss of any atoms from the starting reactants. With the name of the reaction and the fact that it is a [3+2] cycloaddition known, we can reasonably deduce that the next room is room **5**.

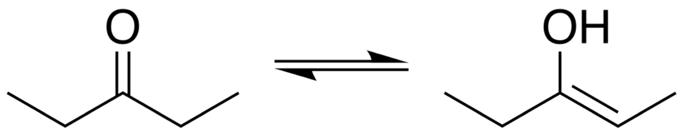
#11: Room 5

You enter the room and prepare yourself for a drawing exercise.

"Of all the stable, isolable structural isomers of C_4H_8O and ignoring stereoisomers, there are in total a ethers, b epoxides, c (non-epoxide) compounds which react with dry HCl under heat, and d compounds which give a reddish-brown precipitate with Fehling's solution. Find the numerical value of (a ✕ b) + (c ✕ d)."

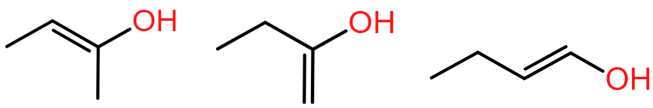
Ignoring stereoisomers, there are 22 isolable structural isomers of C_4H_8O.

Note firstly that enols will not be regarded as isolable isomers, due to their tendency to rapidly undergo keto-enol tautomerism to form its corresponding keto-structure.

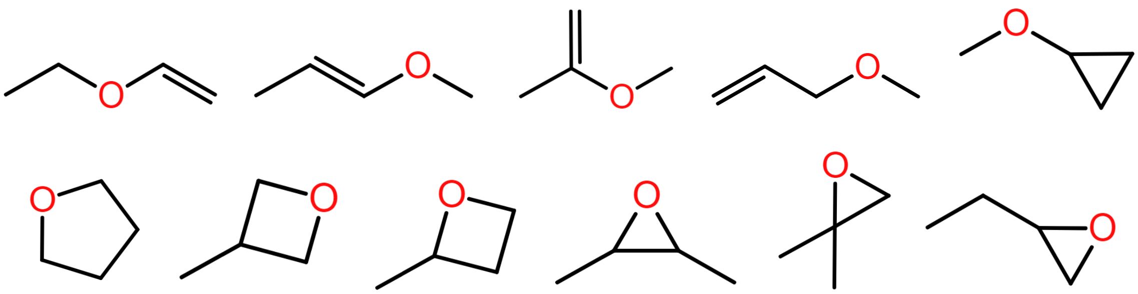


(favoured)

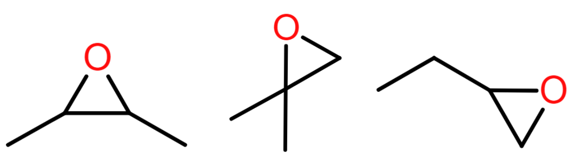
As such, this rules out certain structures, like the following:



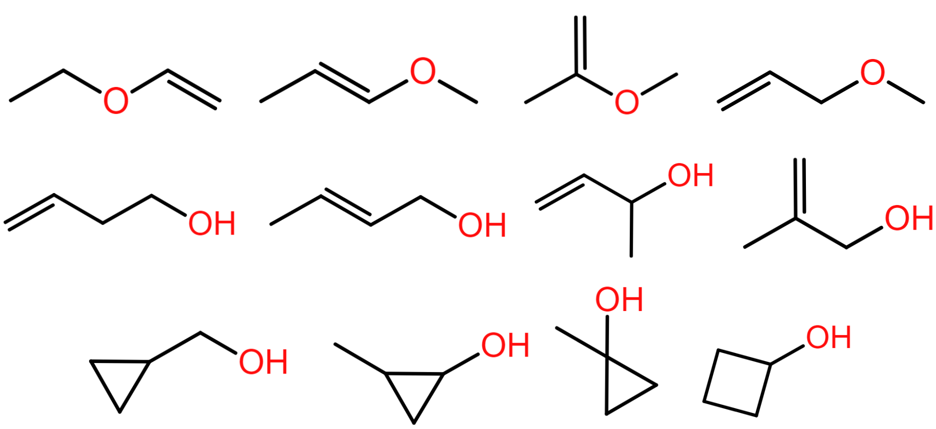
Of the remaining structures, there are 10 ethers, hence ***a*** **= 11**;



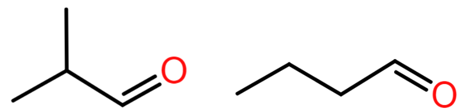
3 epoxides, which are 3-membered cyclic ethers, hence ***b*** **= 3**;



12 non-epoxide compounds which react with dry HCl under heat (alkenes, which undergo electrophilic addition, and alcohols, which undergo nucleophilic substitution, both forming alkyl halides), hence ***c*** **= 12**;



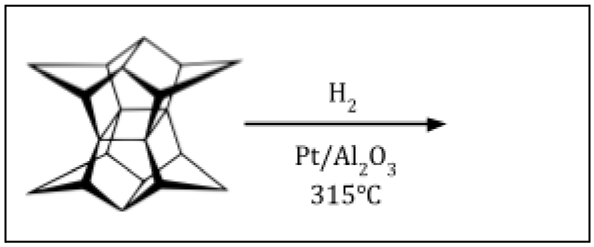
2 compounds which give a positive Fehling's test, forming a reddish-brown precipitate of Cu_2O (the two aliphatic aldehydes), hence ***d* = 2**.



Therefore we find **(*a* × *b*) + (*c* × *d*)** = (11 × 3) + (12 × 2) = 33 + 24 = **57**.

#12: Room 57

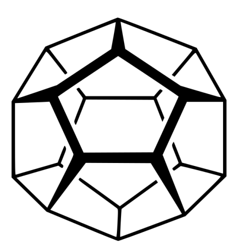
You see the reaction



Solving this clue requires us to deduce the final product of the reaction. The presence of H_2 gas may suggest a reduction reaction, while Pt or Al_2O_3 may serve as a heterogenous catalyst in facilitating the reaction. With that being said, there appears to be not much information to guide us in solving this problem.

One point of entry is to realise that since the starting molecule is not reacted with any carbon-containing species, the number of carbon atoms in the product should remain unchanged (i.e. the product will have the same number of carbon atoms as the reactant). Furthermore, counting the atoms in the reactant gives its molecular formula, $C_{20}H_{20}$. A saturated compound having such a high degree of unsaturation is very rare, and points to a final product with a structure that is almost geometric.

A search on C20 hydrocarbons is likely to yield **dodecahedrane**, $C_{20}H_{20}$, which derives its name from its dodecahedral shape.



The reactant is pagodane, a peculiar molecule which gets its name from its resemblance to a pagoda. The reaction is actually an isomerisation, resulting in no change in the molecular formula of the reactant, and has been documented in literature[1].

With an understanding of the final product, it is reasonable to conclude from its name and structure that the answer is **12**, from its 12 regular faces and the prefix dodeca- meaning 12.

#13: Room 12

You push open the door but it slams into the corner of a long, varnished, antique-looking wooden table, causing it only to open halfway. ***On the table, you find an experimental setup of bygone age, consisting of a grey stone next to an object with a radiation warning labelled on it. You notice the inscriptions "up, down, down" on the stone with the markings of a certain year that has been eroded - 19__.***

The aim of this riddle is the find out the year in which what seems to be a well-known experiment had been conducted. The experiment involves radiation, an unknown grey stone and "u, d, d". Physics students may recognise "u, d, d" as notations for up, down and down quarks, and the subatomic particle with these quark contents is the **neutron**. The most historic experiment involving neutrons and radiation is James Chadwick's discovery of the particle, in which he exposed beryllium to alpha particles produced from the radioactive decay of polonium. The grey stone and radioactive object would be beryllium and polonium respectively (polonium, named after Poland, is also subtly hinted at by the mention of the "polished" table).

This experiment was conducted and the neutron discovered in **1932** - hence the answer is **32**.

#14: Room 32

In this room you find a word ladder, of element names written in the form of a poem - a word ladder is a puzzle with a sequence of words, where adjacent words differ from each other by a single letter.
*"**This hefty solid is nothing new; let***
Us spell out its full name and begin the swaps.
Change one letter and rearrange to get
An element with the rarest pink salts.

[1] Fessner, Sedelmeier, Spurr, Rihs & Prinzbach, 1987; Fessner et al, 1987

Shed one letter and replace with a "c",
Its namesake is a natural satellite.
Swap out one letter and leave the rest be,
You'd rest your gaze upon a nobel sight.

Replace one, switch around and you will find
One element's name that's been lost to time."
What is the atomic number of the element at the start of this word ladder?

It is worth noting that the number of elements that share a large proportion of letters in their names is relatively few. Each clue given in the word letter could also be a viable entry point to deducing the elements. For example, the 3rd element in the word ladder is named after a natural satellite, which is likely a planet or moon, the 4th element possibly discovered, named after or indirectly associated with a Nobel laureate, and the 5th element possessing a name that is no longer in use, for example ferrum for iron or hydragyrum for mercury.

The word ladder is as follows:
barium
erbium
cerium
curium
cuprum

Very little information is given of the starting element barium, except for the mention that it is "hefty", which is apt as barium is named after the Greek word *barys*, meaning "heavy". To reach barium, however, it is much clearer to begin from another element and work our way back up.

Replacing "a" with "e" and rearranging the letters gives erbium, which incidentally forms pinkish compounds in its +3 oxidation state, such as Er_2O_3, ErF_3 and ErI_3. Its "rarest pink salts" possibly also hints at its identity as a rare-earth metal in the f-block of the periodic table.

Replacing "b" with "c" and rearranging the letters gives cerium, named after the dwarf planet Ceres.

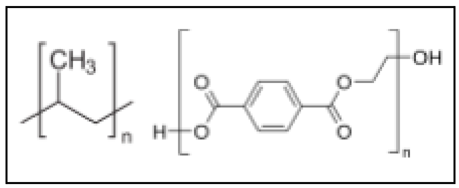
Replacing "e" with "u" gives curium, named in honour of repeat Nobel laureate Marie Curie.

Replacing "i" with "p" and rearranging the letters gives cuprum, which is the Latin name for copper and despite it being no longer used conventionally, is the namesake for its atomic symbol Cu.

The next room is the atomic number of barium, **56**.

#15: Room 56

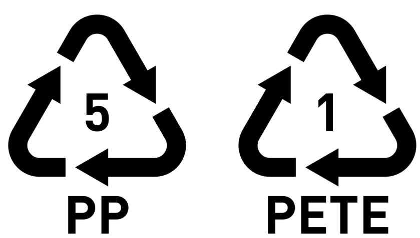
You see the image



What number may their resin identification codes give?

The first thing to notice is that both the structures in the image are polymers, due to their repeating units. Specifically, they are plastics. The polymer on the left is polypropylene (PP), while the polymer on the right is polyethylene terephthalate (PET/PETE).

How are these plastics related to any number? The answer lies in the resin identification code (RIC), which classifies commonly-used plastics by its physical properties to aid in its manufacturing and recycling processes. Plastic items are typically marked with these small labels:



Placing these labels side by side, we can see the numbers associated with each corresponding plastic is 5 and 1 respectively. Scouring through the remaining numbers available, we conclude that the answer is **51**.

#16: Room 51

You find a slip of paper which reads,

> *"**I am named after a quality of a plant. I've served humanity before, much to its dismay. As a result, people have come to associate me with Prussian blue and perhaps Thanatos. What am I?**"*

This mysterious substance with a strange namesake may be hard to pinpoint. After all, what chemical produced in the name of serving humanity has not left its fair share of repercussions? Prussian blue may remind teams of iron given that it is a ferrous ferrocyanide salt. However, Thanatos, or the personification of death may suggest that our substance in question is toxic. This is a more essential clue as toxic compounds typically point to a few select elements like arsenic, mercury or thallium.

This substance is indeed **thallium**, which derives its name from the Greek *thallós* and apparently refers to the green colour of a twig or branch. It is named as such due to its striking green spectral line, as well as the green colour its salts produce in a flame test.

Due to its toxicity, thallium salts were historically used as a pesticide in the 1920s before being repurposed to rodenticides. However, these products quickly became phased out in the 1960s after fatal cases of thallium poisoning were reported in humans.

Surprisingly, pharmaceutical Prussian blue is used as an antidote to thallium poisoning due to its ability to sequester thallium ions and other heavy metal ions from the body. In addition, Thanatos, as the last Horseman in the Four Horsemen of the Apocalypse, is commonly depicted riding a pale horse - incidentally the title of an Agatha Christie novel which features the symptoms of thallium poisoning.

The next room is room **81**, the atomic number of thallium.

#17: Room 81

> *You see a sealed bottle of unknown liquid. Its label writes:*
> ***"Chemists use it often, as do criminals. It is both solvent and sedative. It is notoriously misunderstood by popular culture - its action is slower than expected. Leave it out in the air and you get a dangerous chemical weapon. Its danger has made it R-rated. Add a powerful base and you have a cyclopropanating agent. It is marketed as a Freon - but which one?"***

This riddle features a versatile substance - we're told that it's a solvent and sedative, but considering its usage in criminal underworld, it may also be a toxin, or a synthetic intermediate leading to some illicit chemicals. It is also volatile, given that it vaporises and reacts when left out in air.

In addition, it is “notoriously” misunderstood because “its action is slower than expected”. At first this may suggest some kind of drug, but considering its use as a solvent it is likely to be a relatively simple molecule. This could eliminate the various abused substances commonly featured in TV, like LSD or cocaine, as well as toxins like tetrodotoxin. In conjunction with the clue that it is marketed as a Freon, which are most commonly applied to chlorofluorocarbons (CFCs) and their derivatives, we have narrowed our search to some kind of simple halogenated carbon compound.

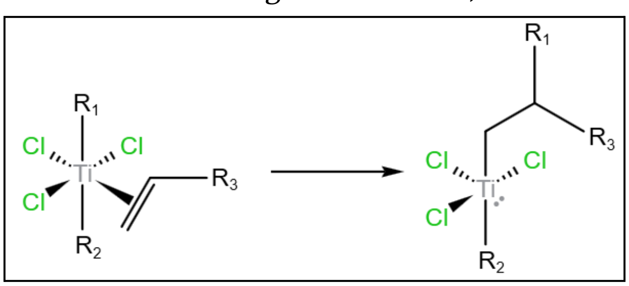
This combination of clues may suggest **chloroform**. Chloroform is a popular organic solvent for chemists, but also a sedative and anaesthetic that is misused by criminals. When left to vaporise in the open, it slowly oxidises to phosgene gas, $COCl_2$ - its extreme toxicity had led it to be used as a chemical weapon in World War I as a pulmonary irritant.

$$2CHCl_3 + O_2 \rightarrow 2COCl_2 + 2HCl$$

A major industrial use of chloroform is in refrigerants, which is indicated in the final line. Refrigerants are typically identified by the prefix R-, such as R-12 for CF_2Cl_2. In a similar vein, chloroform is identified by R-20, and also commonly known by its brand name **Freon 20** under the trademark of the Chemours Company. 20 appears to be the best number which chloroform is labelled by, and hence we go to room **20**.

#18: Room 20

You see a note with the following reaction on it, with the number:



Nobel Prize of 19___

Similar to what we have seen in room 12, this clue requires us to figure out the year that a Nobel Prize was awarded for research associated with this strange reaction. As we see a titanium atom coordinated to a terminal alkene, this image depicts an organotitanium reaction which involves the coupling of an alkene to a hydrocarbon group.

Transition metals in organic reactions typically function as catalysts, which is the case for this titanium chloride species. From the reaction, we are able to extrapolate the subsequent steps: the lone pair formed on the titanium atom allows titanium to coordinate to the next terminal alkyne, repeating the cycle depicted in the image and causing the hydrocarbon chain to extend in a polymerisation reaction.

Titanium-based catalysis involved in the chain polymerisation of terminal alkenes were first researched upon by chemists Karl Ziegler and Giulio Natta. The work done by the pair won the **Nobel Prize in Chemistry in 1963**, and the range of catalysts developed to this end became known as Ziegler-Natta catalysts. The missing number at the bottom is **63**.

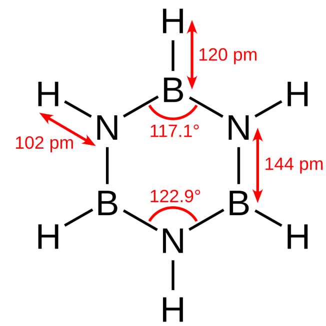
#19: Room 63

You open the door to find a fume hood (really? In a dungeon? Was that where the noise was coming from?) with a beaker of unknown colourless liquid inside it. A note next to the beaker reads,
*"**This chemical has many similarities to its multifaceted cousin, '66'. They both possess a certain chemical property which we are more commonly accustomed to see in an organic context. Splitting its common name in half, the first part of its name shares an inexplicable similarity to a symbol characteristic to '66'... Even though that was not what it was named after. '66' is to this chemical's cousin as __ is to this chemical.**"*

We are given information of an unknown colourless liquid, which is an analogue to another compound called "66". They may be compounds in the same homologous series, or share similar physical and chemical properties. Notably, "66" also has a characteristic symbol that is associated with it.

Perhaps the most promising clue is "They both possess a certain chemical property which we are more commonly accustomed to see in an organic context." What are properties that are most salient in organic compounds but may be applied to inorganic compounds as well? Some that may come to mind are chirality, electrophilicity / nucleophilicity, hydrogen bonding, …. aromaticity?

The unknown compound is actually **borazine**, with chemical formula $\mathbf{B_3H_6N_3}$, and commonly termed the "inorganic benzene".



Compound “66” is hence benzene, with the cryptic name derived from its molecular formula C_6H_6. A symbol characteristic to benzene is the ouroboros, from which its cyclic structure is deduced, and which the first half of borazine’s name, bora-, indeed bears a resemblance to. Being isoelectronic with benzene, borazine is also aromatic, having pi electrons delocalised above and below its planar structure.

Just as benzene, C_6H_6, is described as “66”, with the numbers representing the number of each element in its molecular formula, we can describe borazine, $B_3H_6N_3$, as **363**. The other permutations of the numbers, 336 and 633, do not correspond to any room number.

In the case that teams have traversed all previous 18 rooms in the correct order, it is not necessary to solve the clue in this room to complete the dungeon crawl. In fact, upon reaching **room 20**, teams are already able to deduce that the order for completing the journey is room 20 → room 63 → room 363, given that room 363 is the exit. Upon reaching the previous room, **room 81**, teams only have to decide between choosing rooms 20 and 63, in order to obtain the passcode to leave the dungeon.

CC3: The Great Organic Guessing Game

Crossword puzzles are a simple pastime commonly enjoyed by people of all ages, and because chemistry is also something so beloved by students, there awaits a fun little chemistry-based crossword puzzle that must be solved to attain specific letters, which when arranged correctly, will allow you to deduce a specific compound **A** that will be the answer to the puzzle as a whole.

As such, first off, please solve the following crossword puzzle.

ACROSS

3. Fast food, or a famous rearrangement of some aromatic species?
5. Zinc enolates; consult the Blaise reaction!
7. *(See reaction schemes)*
8. Two successive pericyclic steps, the first of which involves an alkene.
10. This one's a Favorskii-type rearrangement. But what exactly is it? *(See reaction schemes)*
13. One of the DMSO oxidations.
15. What precedes a Horner-Wadsworth-Emmons olefination?
16. "Pretty much the same as Bischler-Napieralski", according to my friends.
17. *(See reaction schemes)*
19. *(See reaction schemes)*
21. The asymmetric form of Robinson annulation.
22. A well-known American conservative commentator, or an olefination reaction.
24. An alternative to Upjohn dihydroxylation.
25. Photochemical reaction of some sort?
26. An alternative to DIBAH for reducing nitriles.
27. *(See reaction schemes)*

DOWN

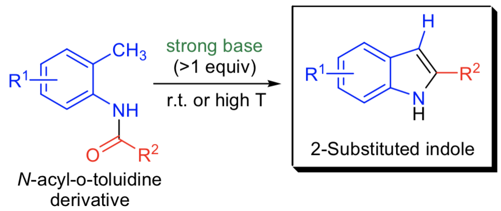
1. *(See reaction schemes)*
2. "DEAD" might be an understatement.
4. *(See reaction schemes)*
6. Two different oxidations with similar conditions usually lumped together.
9. The name of an organic textbook, and a coupling with titanium.
11. Carbon monoxide, hydrochloric acid and a catalyst, oh my!
12. A synthesis of an aromatic heterocycle using Grignard reagents.

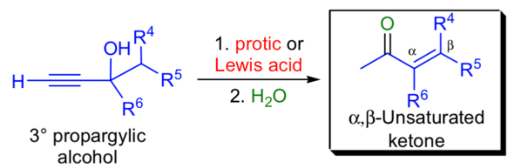
14. *(See reaction schemes)*
18. Under the same conditions, cyclopropanation of alkenes also occurs
20. Lewis acid-catalyzed electrocyclic reaction.
23. *(See reaction schemes)*

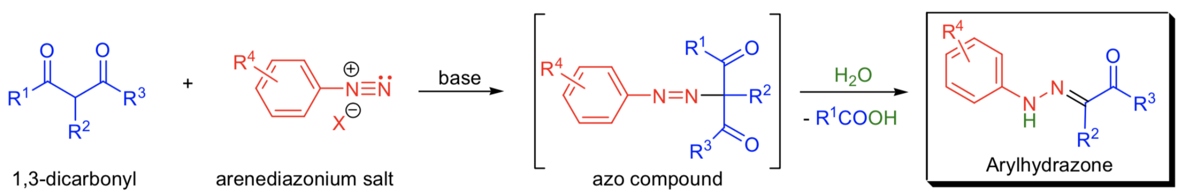
Please ignore hyphens or apostrophes; for example, the Schotten-Baumann reaction should be rendered as **SCHOTTENBAUMANN**.

Reaction Schemes for Crossword

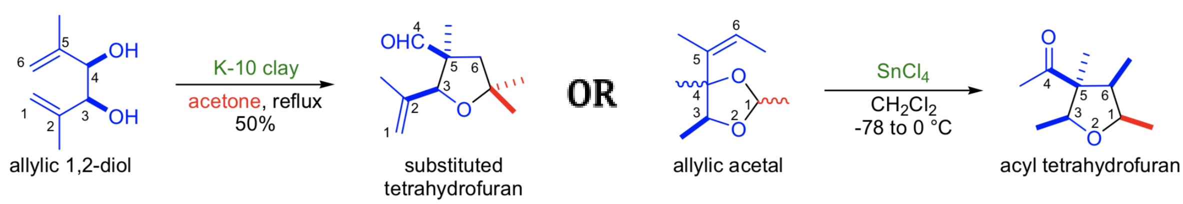
Seven reaction schemes depicting famous named reactions are given below. Their names are answers to the crossword puzzle clues above, all of them in some order which you must deduce.

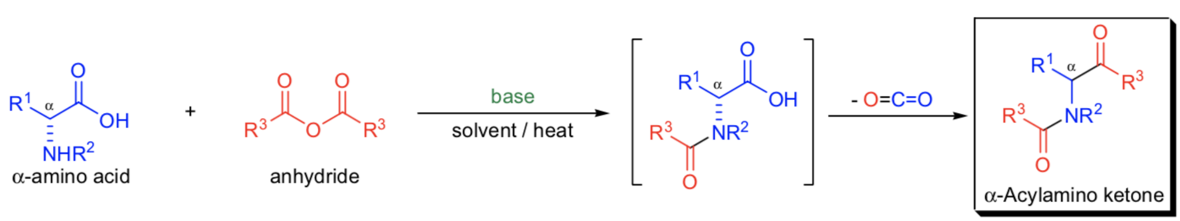




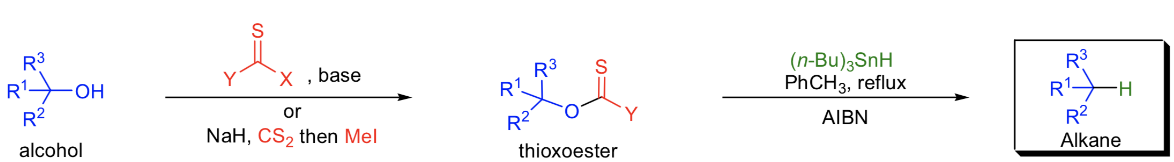


R^1 = alkyl, aryl; R^2 = H, alkyl, aryl, acyl, CN, Cl, Br; R^3 = *O*-alkyl, *O*-aryl, OH; R^4 = electron-withdrawing or electron-donating groups

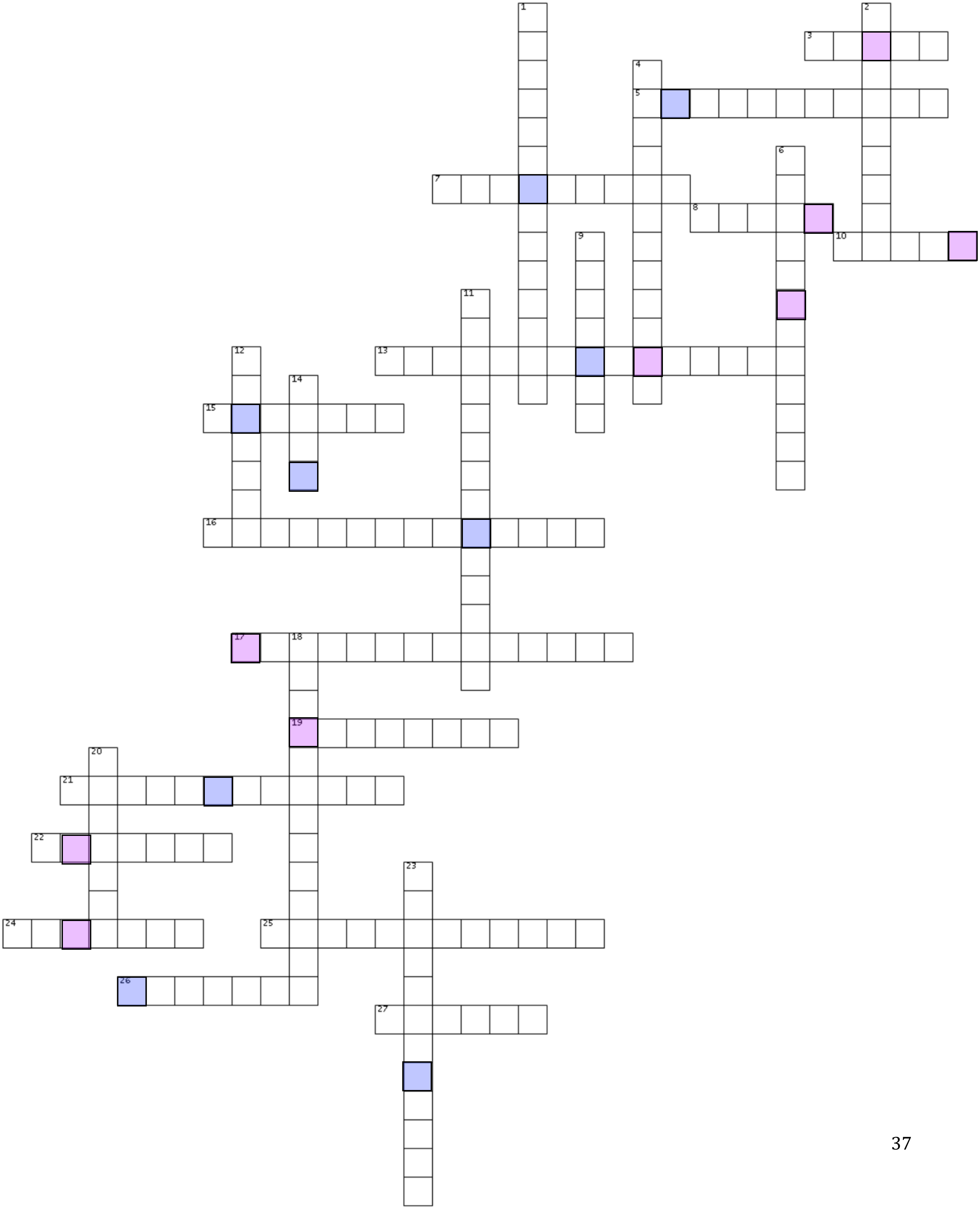




R^1 = H, alkyl, substituted alkyl; R^2 = H, alkyl, substituted alkyl, aryl, heteroaryl; R^3 = Me, Et, *n*-Pr; base: pyridine, alkylpyridine, NaOAc; solvent: pyridine, Et_3N



Y = SMe, imidazolyl, OPh, OMe; X = Cl, imidazolyl; base: NaH



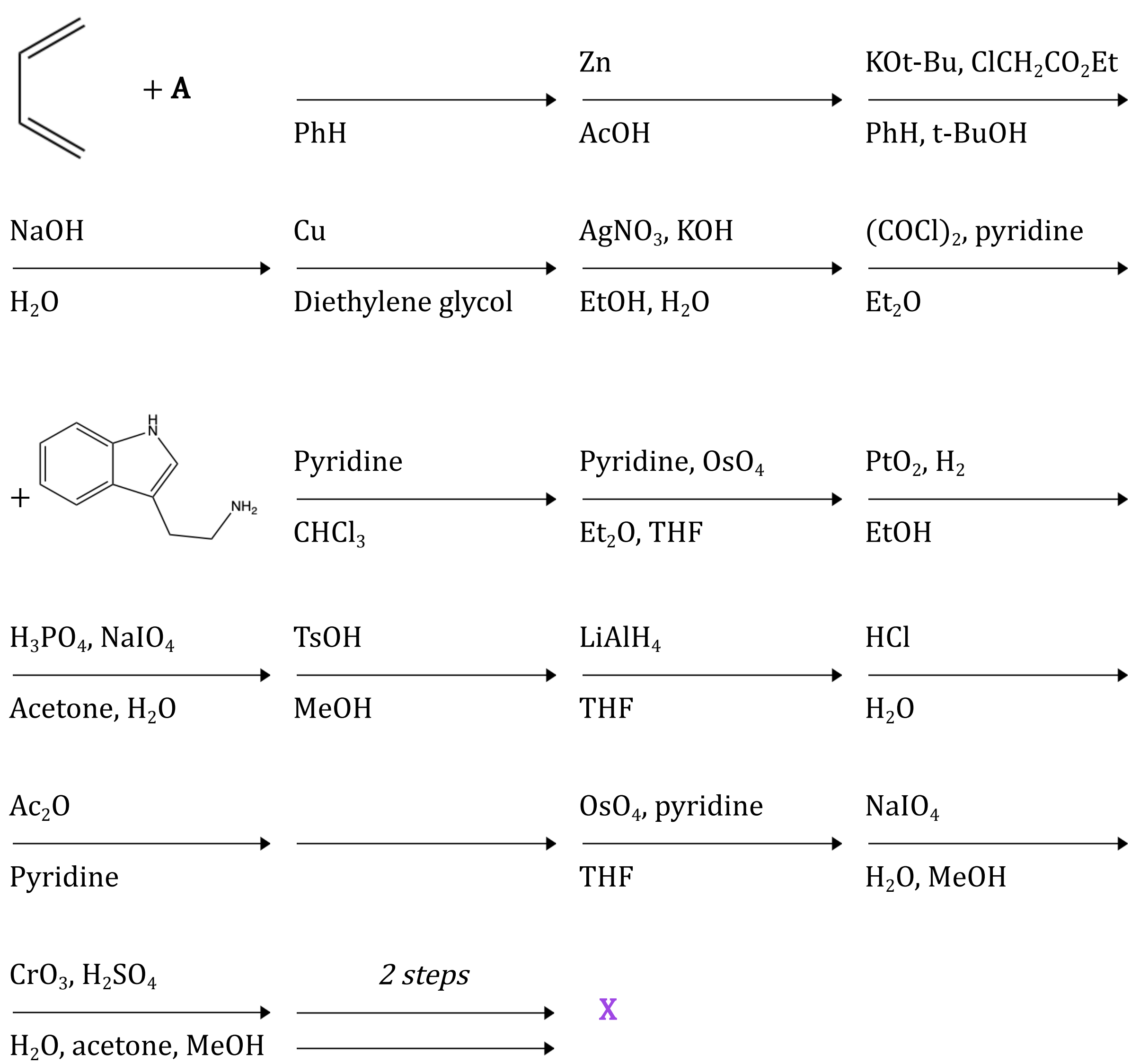
Had fun?

You might have noticed that some of the squares above were marked in blue or purple.

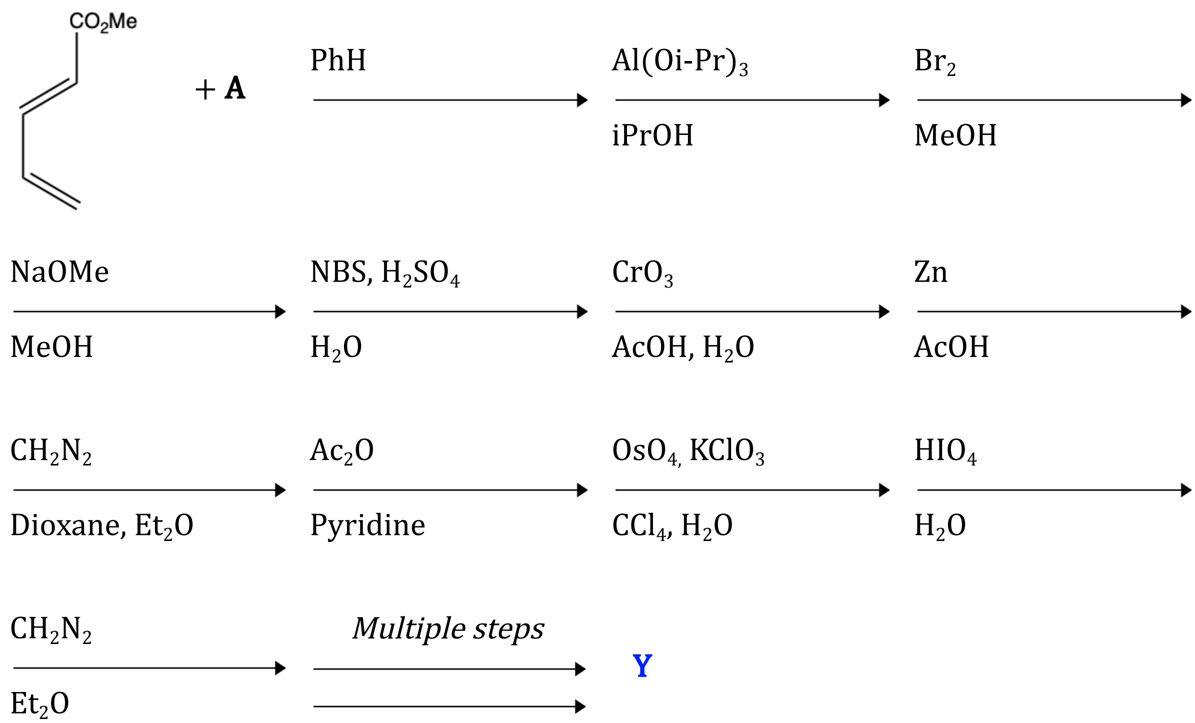
The letters in the **purple** squares (9 in total) spell out the name of a certain natural product, **X**. Likewise, the letters in the **blue** squares (9 in total) spell out the name of a different natural product, **Y**.

The two natural products can both be synthesised with the common starting material **A**. The synthetic schemes are provided below.

Formal synthesis of **X:**



Formal synthesis of ***Y:***



Deduce the structure of **A**.

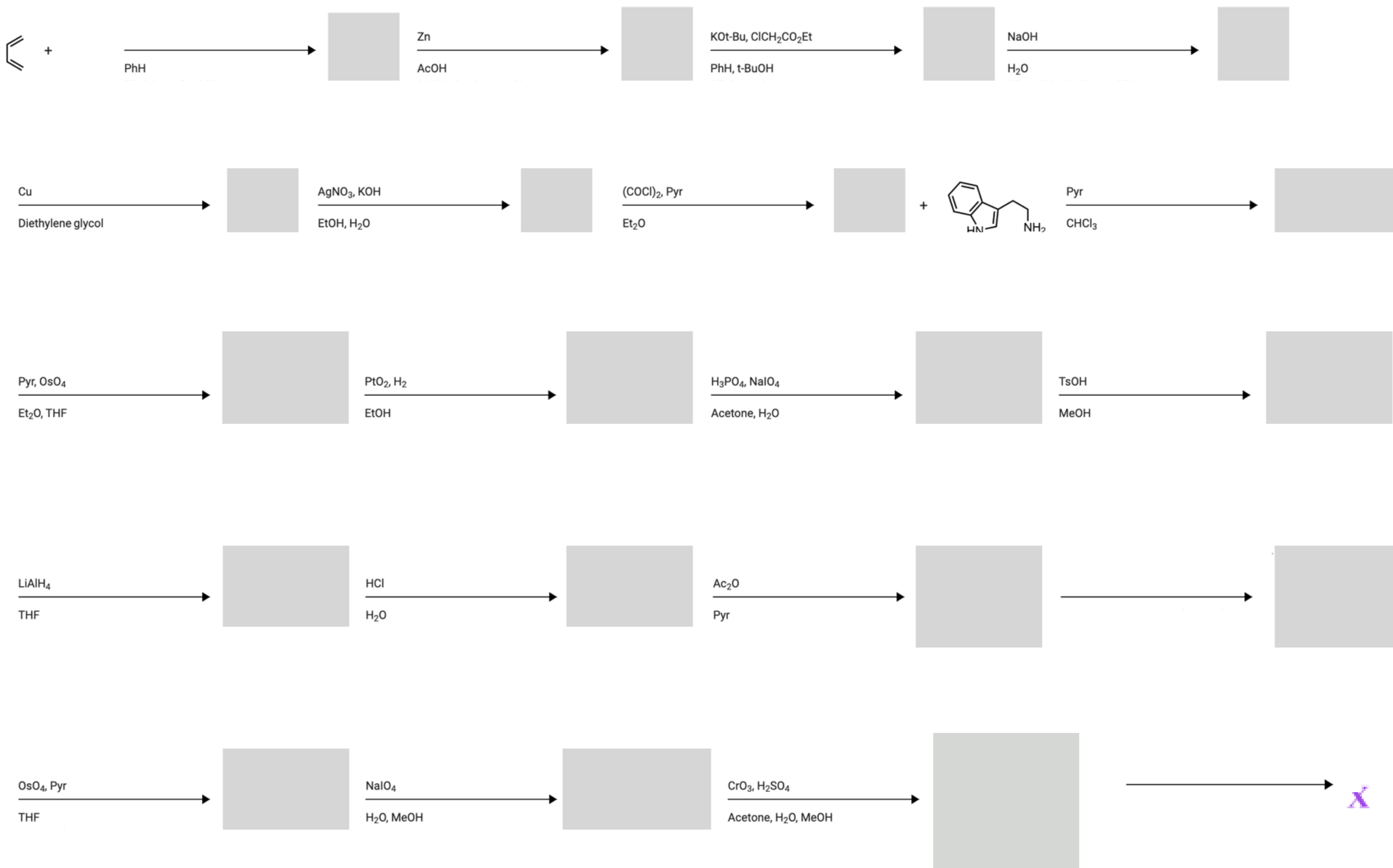
Stereochemical details are not required, if any.

Note: you are not expected to solve the synthetic scheme, nor is it expected to be possible. Use relevant resources to find the relevant total syntheses once you deduce **X** and **Y**.

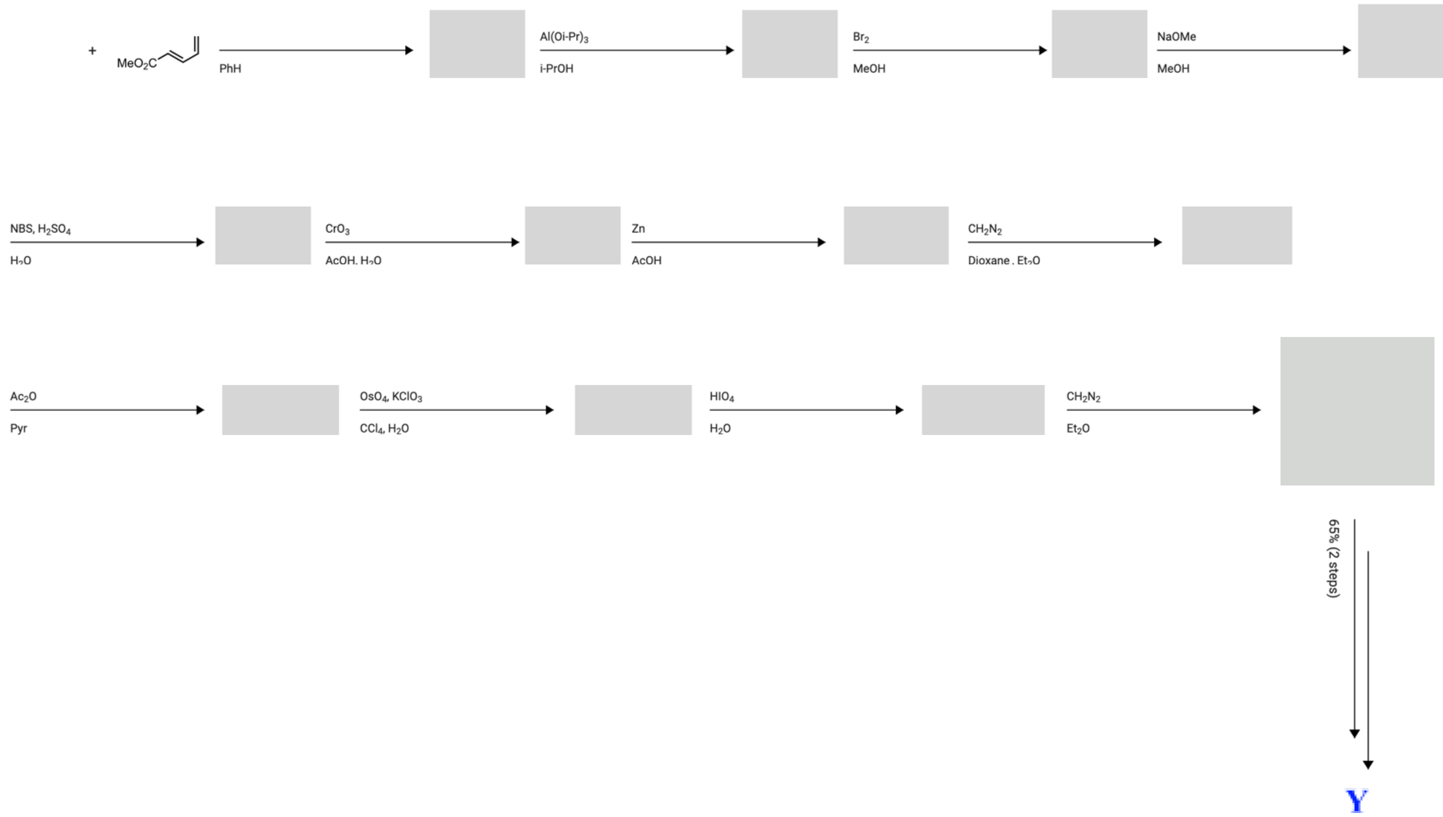
The original reaction schemes have been provided in the appendix below.

Appendix:

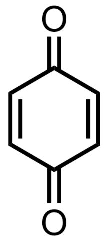
Formal synthesis of X:



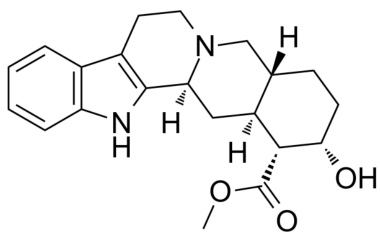
*Formal synthesis of **Y**:*



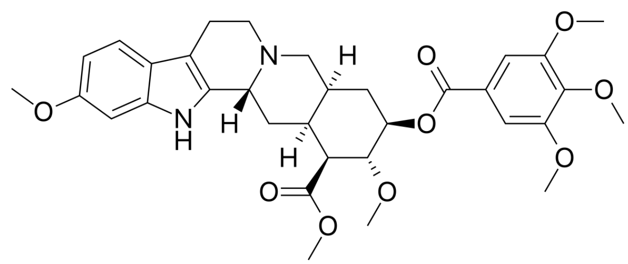
Solution:

A has the structure 

On solving the crossword, the letters in the purple squares spell out the natural product **X**: **yohimbine**, and the letters in the blue squares spell out the natural product **Y**: **reserpine**, which have the following structures:

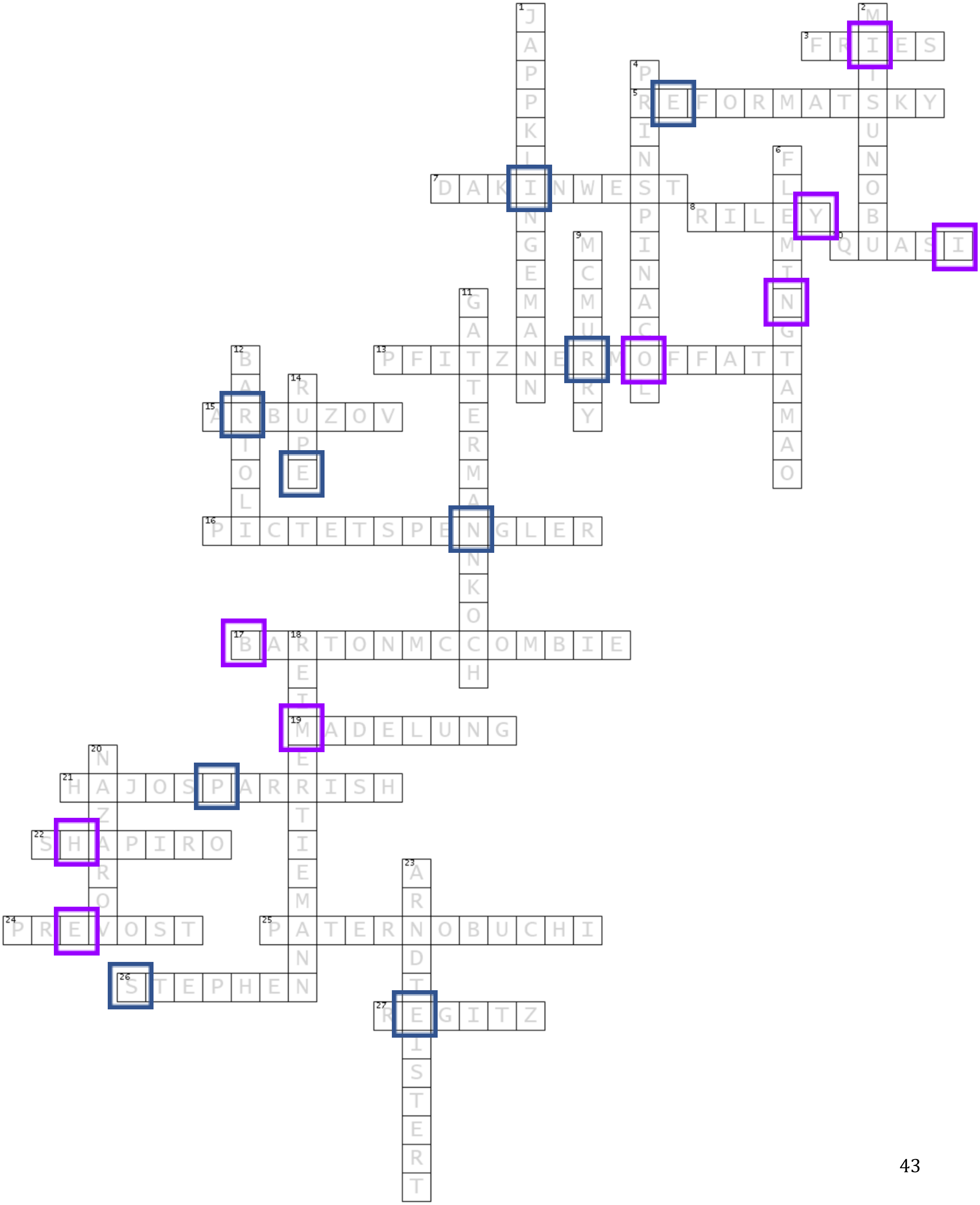


Yohimbine



Reserpine

The answers to the completed crossword is as follows:


1 JAPPKLINGEMANN
2 MITSUNOBU
3 FRIES
4 PRINSPINACOL
5 REFORMATSKY
6 FLEMINGTAMAO
7 DAKINWEST
8 RILEY
9 MCMURRY
10 QUASI
11 GATTERMANNKOCH
12 BARTOL
13 PFITZNERMOFFATT
14 RUPE
15 ARBUZOV
16 PICTETSPENGLER
17 BARTONMCCOMBIE
18 RETMERTIEMANN
19 MADELUNG
20 NAZAROV
21 HAJOSPARRISH
22 SHAPIRO
23 ARNDTEISTERT
24 PREVOST
25 PATERNOBUCHI
26 STEPHEN
27 REGITZ

CC4: 0, 492, 32, 273

Huahua has accidentally spilled some acetone on 4 samples, washing off their labels. Fortunately, the melting point of each sample is still visible: 0 °C, 492 °R, 32 °F and 273 K… unfortunately, they are all the same melting point (or, at least, close enough that his melting point determination apparatus will not be able to tell them apart).

Can you help Huahua to identify the samples?

Part I: 0

Huahua clearly remembers how this sample was synthesised and all the relevant properties. However, he remembers **zero** data! Can you deduce the substance **A** without any data?

Huahua's notebook

Substance **A** comes from two other substances reacted together, **B** and **C**. In the reaction, side product **D** is also formed.

B is a linear molecule with rather weak bonds, and can be synthesised using two gases in a rather straightforward reaction. It was first produced a few years before Singapore became independent. The bonds in **B** are weak, each having a bond order of 1/2. **B** is a powerful antiseptic as well as a tool to etch titanium and other metals.

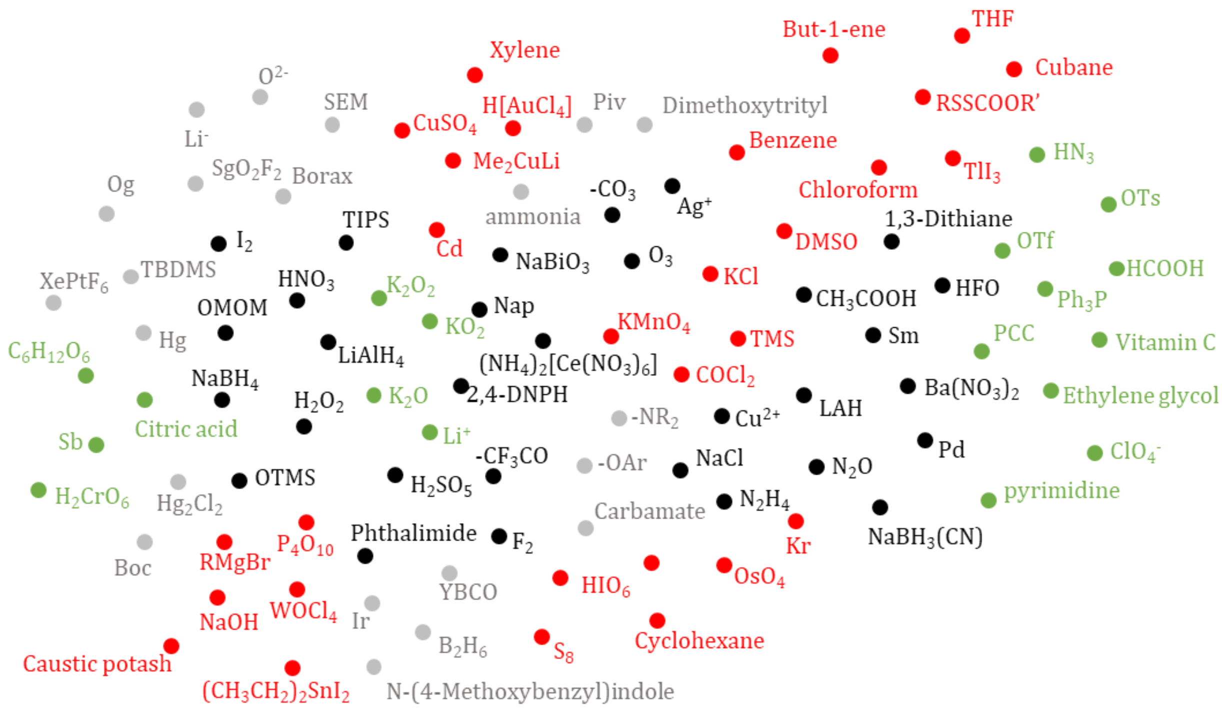
C is an extremely strong acid and also a useful oxidising agent. In the anhydrous state, it is not stable. **C** also forms an azeotrope with water. Interestingly, **C** is rated a 3 in terms of flammability and instability-reactivity on the fire diamond, but is rated a 0 for health. And as expected, it has an OX rating.

A doesn't really have much information about it. It is a yellow solid though. Meanwhile, **D** is a poisonous gas or liquid, which has a relatively higher boiling point compared to its homologues. It has important industrial applications such as a precursor to Teflon, a catalyst and a good solvent.

*Identify substance **A**.*

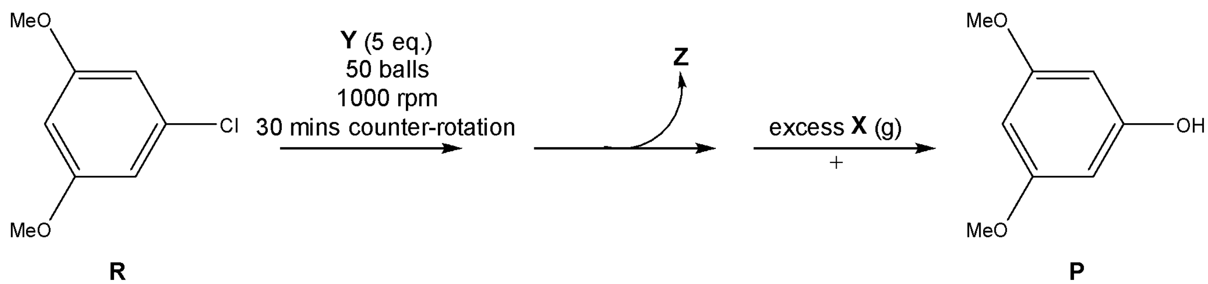
Part II: 492

Huahua enjoys sketching and drew a picture of **E** while waiting for it to be ready. However, he did not realise that the picture got slightly smudged, and now he does not know which parts of his diagram are relevant. Luckily, he had one level of protection on his diagram. *Deduce substance **E**, by first identifying all the protecting groups in the diagram.*



Part III: 32

Huahua's curiosity about this substance, **X**, led him to investigate what it can be used for. He discovered an interesting reaction scheme involving this substance, **X**. It involves a reaction between organic substance **R**, and a substance **Y** found in minute traces in all samples of **X**. **Y** can also be produced by bombarding gas **Z** with neutrons, followed by igniting the reaction mixture with oxygen. The reaction is as follows:



1. **R** is added to 5 equivalents of **Y** in a planetary ball mill container. 50 stainless steel balls are added and the rotation set to 1000 rpm, with the direction reversing every half an hour. This proceeds for 3 hours.
2. The product of the rotation is purified, during which gas **Z** spontaneously evolves.
3. A large excess of gaseous **X** is added to the purified product, following which product **P** is formed.

*Identify substance **X** using the reaction scheme.*

Part IV: 273

In his spare time, Huahua enjoys designing puzzles. To his surprise, the information about the last substance was found in the latest maze he drew. He does not remember which entrance or exit he used, but he knows the steps he took to reach the end, and that the colours of each cell correspond to the colours of the relevant compound. (If a precipitate is formed in that step, take the colour of the precipitate, while in all other cases take the colour of the compound formed. ***Ignore colours of any reagents added and side products***). Note that the colour in the cell is not necessarily 100% representative of the actual colour.

grey	brown	brown	blue	red	orange
brown	green	orange	yellow	yellow	yellow
grey	pink	white	black	blue	brown
blue	purple	dirty green	purple	orange	red
black	blue	green	white	black	red
red	white	pink	purple	blue	pink

a. From the starting compound (a transition metal oxide), add hydrochloric acid.
b. Add solid tin to the solution.
c. Excess alkali added to the solution.
d. Add solid zinc and concentrated hydrochloric acid to the solution.
e. Excess alkali added to the solution.
f. Acidified potassium permanganate added to the solution.
g. Oxone added to the solution.
h. Add $SOCl_2$.

i. Add excess EtOH to the solution.

Identify the final substance: it is the substance at the end of the maze (the final substance has the colour of the exit).

Now that you have identified all the compounds, to claim your prize, key in the **sum** of the **four CAS Registry Numbers**, omitting any dashes. For example, if you believe all four compounds to be Vitamin C, which has a CAS number of 50-81-7, key in 203268, which is 50817 + 50817 + 50817 + 50817.

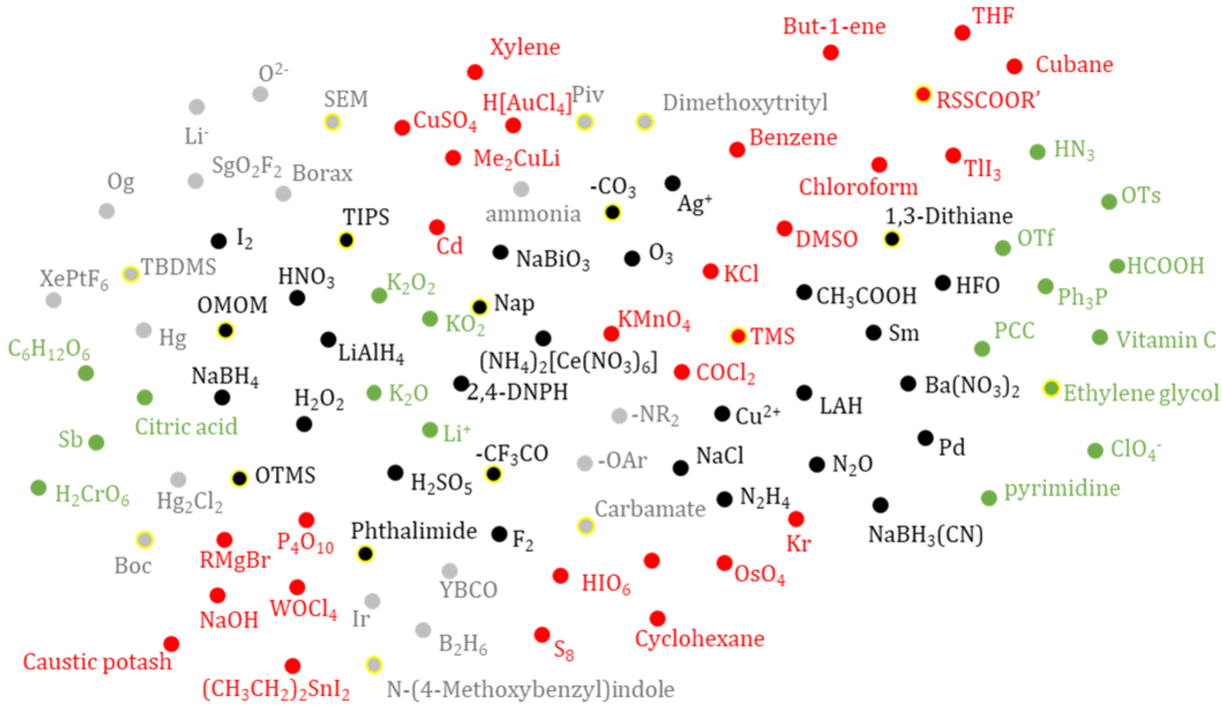
Solution:

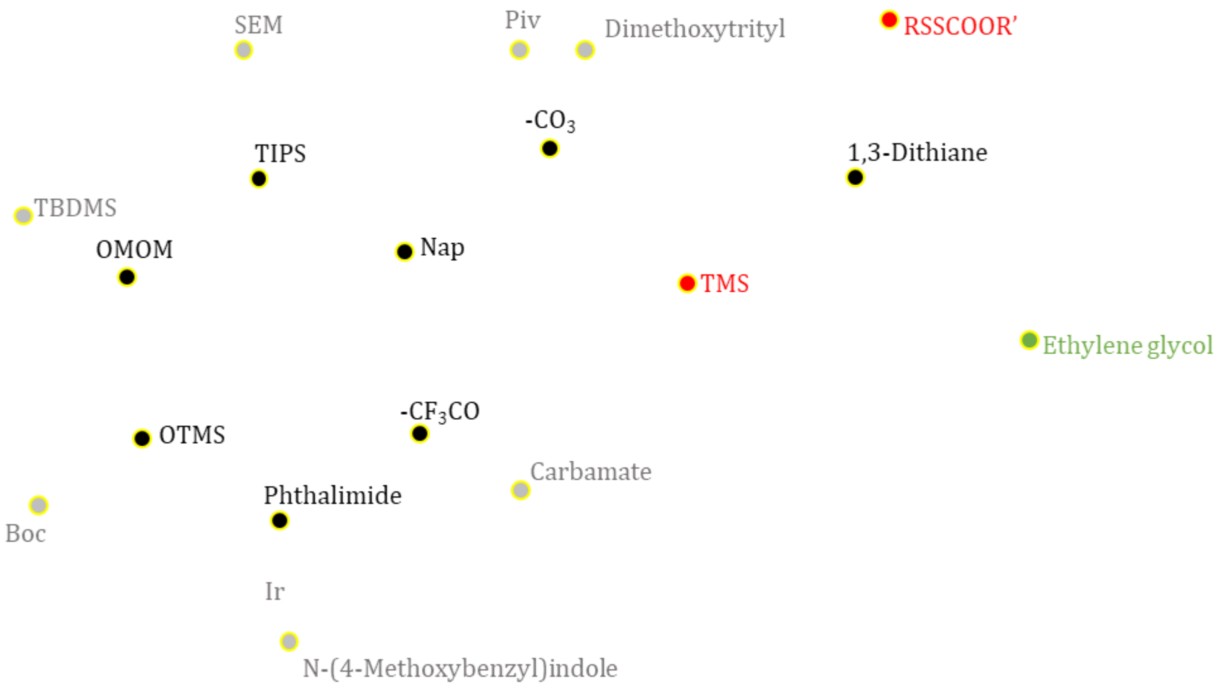
35443737

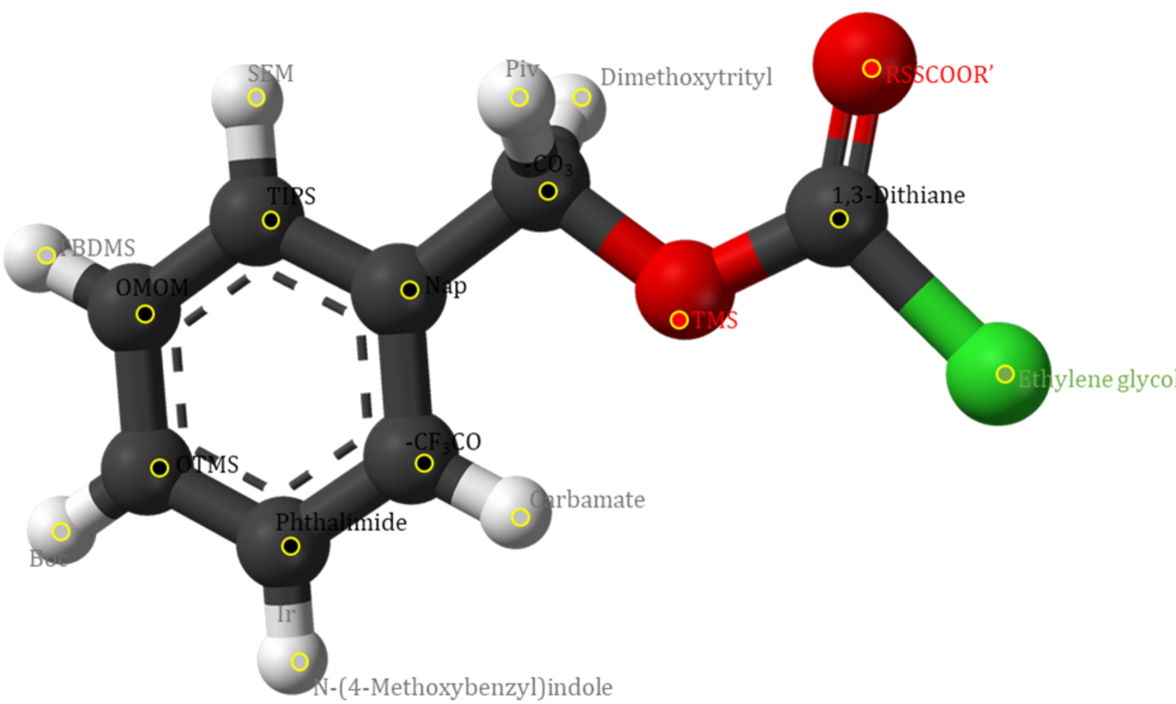
1. **A** is $Xe(ClO_4)_2$ (25523-79-9)

B is XeF_2 while **C** is $HClO_4$. **D** is HF.

2. **E** is CbzCl (501-53-1)

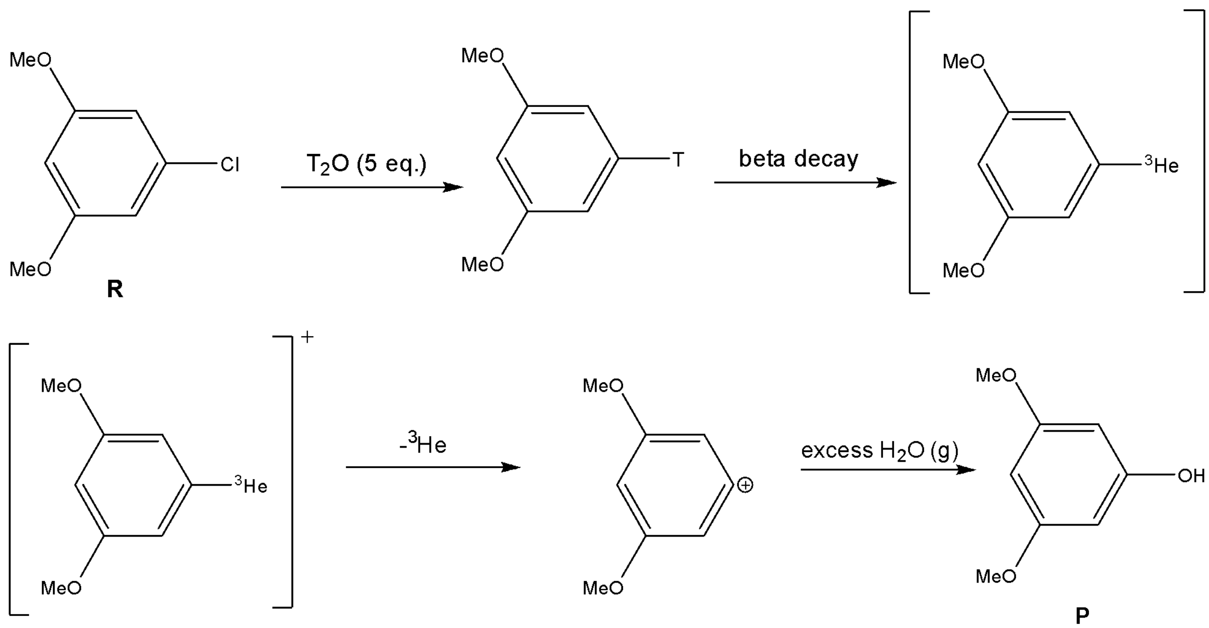






3. **X** is water (7732-18-5)

Y is T_2O (superheavy water), **Z** is helium-3. The reaction is as follows:



4. The final compound is $VO(OEt)_3$ (1686-22-2)

The transition metal involved is Vanadium. The path of the maze is highlighted in dark red:

grey	brown	brown	blue	red	orange
brown	green	orange	**yellow**	**yellow**	**yellow**
grey	pink	white	**black**	blue	**brown**
blue	purple	**dirty green**	**purple**	orange	red
black	**blue**	**green**	white	black	red
red	white	pink	purple	blue	pink

a. From the starting compound, add hydrochloric acid. *[VO_2 to VO^{2+}]*
b. Add solid tin to the solution. *[VO^{2+} to V^{3+}]*
c. Excess alkali added to the solution. *[V^{3+} to $V(OH)_3$]*
d. Add solid zinc and concentrated hydrochloric acid to the solution. *[$V(OH)_3$ to V^{2+}]*
e. Excess alkali added to the solution. *[V^{2+} to $V(OH)_2$]*
f. Acidified potassium permanganate added to the solution. *[$V(OH)_2$ to VO_2^+]*
g. Oxone added to the solution. *[VO_2^+ to V_2O_5]*
h. Add $SOCl_2$. *[V_2O_5 to $VOCl_3$]*
i. Add excess EtOH to the solution. *[$VOCl_3$ to $VO(OEt)_3$]*

Our final answer is 25523799 + 501531+ 7732185 + 1686222 = 35443737