Filtering Out Impurities

High-grade solvents that are free from impurities are required for most chemical experiments; these chemicals are usually supplied from a reputable source. *ChemSupplier* is currently in need of a design for a filter to allow them to start producing impurity free solvents. The previous chemist who was tasked with this job used the Lewis structure model as a basis for their filter design, but their product was a failure. This model did not adequately account for repulsion between the electrons in molecules and as a result the solvents were still contaminated with impurities after filtration.

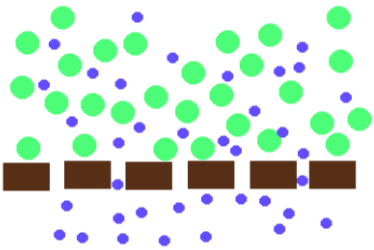

Figure 1. Size exclusion filters separate smaller particles from larger ones.

You have been tasked by the company *ChemSupplier* to design filters that can separate impurities from a solvent by the molecular size of those impurities. Size exclusion filtration is a method that isolates impurities from solvents by entrapping larger molecules while allowing smaller molecules to pass through when the solution is run across the filter.

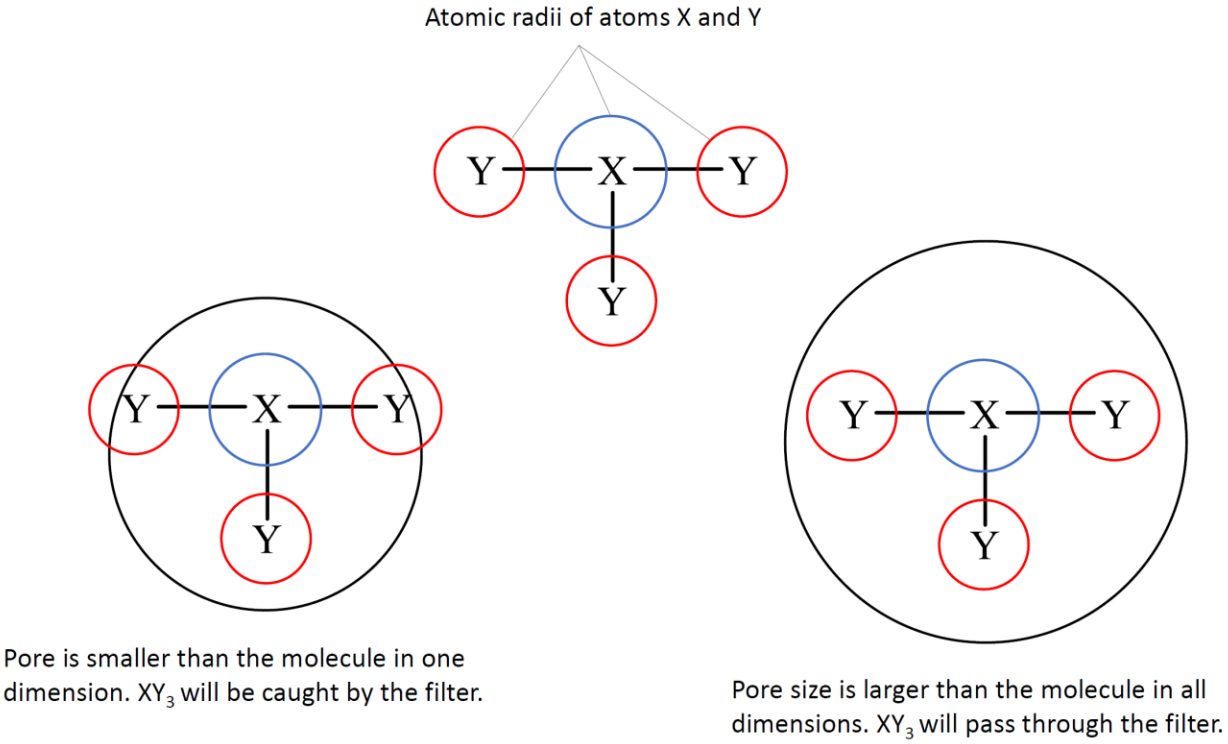

Figure 2. For a size exclusion filter to efficiently remove impurities, the size of the filter's pores must be smaller than that molecule in at least one dimension. If the molecule is smaller than the pore in all dimensions, then it will be allowed to pass through.

To ensure that your product is highly marketable and applicable to different solvents, *ChemSupplier* has requested that the pores be made in line with idealized bond angles for molecules and that the pores for your filter are perfectly circular.

Table 1. Idealized bond angles for different molecular geometries.

Geometry	**Bond Angle (deg)**
Linear	180
Tetrahedral	109.47
Trigonal pyramid	100
Trigonal bipyramidal	120 and 90
T-shape	180 and 90

You have decided to aim at being able to filter the impurities CS_2, ClF_3, PCl_3, and PCl_5 from your solvent, CCl_4. ***This means that you must design a filtration process after which you will be left with pure CCl_4.*** Instead of using the Lewis structure approach, you have decided to use the valence shell electron pair repulsion theory as your model.

Table 2. Bond lengths for the relevant solvent and impurity molecules.

Molecule	**In Solution**	**Bond Length (pm)**	
CS_2	Solute	C=S	155
ClF_3	Solute	Cl–F	163
PCl_3	Solute	P–Cl	203
PCl_5	Solute	P–Cl	203 (equatorial) 219 (axial)
CCl_4	Solvent	C–Cl	177

You must use your knowledge of molecular shapes and sizes to determine how big the circular pores for your filter should be. Be sure to consider that impurities are suspended in fluid and are free to rotate in three-dimensional space. The diameter of the pore must not be smaller than the molecule at any point in its cross-section at any orientation for a molecule to be able to consistently pass through a pore in your filter. It is important to consider the size of atoms as well as the bond lengths in molecules. In other words, the greatest distance of a 3-D molecule between any two points cannot be smaller than the diameter of the pore for it to effectively filter.

Table 3. Atomic radii for the elements contained in each of the solvent and impurity molecules.

Atom	**Atomic radius (pm)**
Carbon	77
Chlorine	99
Fluorine	72
Phosphorus	110
Sulphur	104

Would you require multiple filtrations with different filters; if so, what are the sizes required? *ChemSupplier* is also interested in knowing if there are any impurities that cannot be filtered.

Hint: Consider using the sine law to determine the sizes of 3-D molecular shapes of the molecules

Shareholders are upset that your predecessor failed, so *ChemSupplier* would also need you to explain to shareholders why the idealized angles provided are not exactly the same as the realistic angles one would find if they ran tests upon the substances. How do the real bond angles observed in molecules compare to the ones provided in Table 1? You will also need to explain why your predecessor who used Lewis structures failed and how you have fixed their mistake.