The Contact Process is used in the manufacture of sulfuric acid. This module explains the reasons for the conditions used in the process by considering the effect of proportions, temperature, pressure, and catalyst on the composition of the equilibrium mixture, the rate of the reaction, and the economics of the process. The Contact Process:

- Step 1: Make sulfur dioxide
- Step 2: Convert sulfur dioxide into sulfur trioxide (the reversible reaction at the heart of the process)
- Step 3: Convert sulfur trioxide into concentrated sulfuric acid

**Step 1: Making sulfur dioxide**

This can either be made by burning sulfur in an excess of air:

\[ \text{S}_2(s) + \text{O}_2(g) \rightarrow \text{SO}_2(g) \tag{1} \]

or by heating sulfide ores like pyrite in an excess of air:

\[ 4\text{FeS}_2(s) + 11\text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s) + 8\text{SO}_2(g) \tag{2} \]

In either case, an excess of air is used so that the sulfur dioxide produced is already mixed with oxygen for the next stage.

**Step 2: Converting sulfur dioxide into sulfur trioxide**

This is a reversible reaction and exothermic.

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \qquad \Delta H = -196 \text{ kJ/mol} \tag{3} \]

A flow scheme for this part of the process looks like this:
Step 3: Converting sulfur trioxide into sulfuric acid

This cannot be done by simply adding water to the sulfur trioxide; the reaction is so uncontrollable that it creates a fog of sulfuric acid. Instead, the sulfur trioxide is first dissolved in concentrated sulfuric acid:

$$H_2SO_{4 (l)} + SO_{3(g)} \rightarrow H_2S_2O_{7 (l)} \label{4}$$

The product is known as **fuming sulfuric acid** or **oleum**, which can then be reacted safely with water to produce concentrated sulfuric acid - twice as much originally used to make the fuming sulfuric acid.

$$H_2S_2O_{7 (l)} + H_2O_{(l)} \rightarrow 2H_2SO_{4 (l)} \label{5}$$

Explaining the conditions

The mixture of sulfur dioxide and oxygen going into the reactor is in equal proportions by volume. Avogadro's Law says that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. That means that the gases are going into the reactor in the ratio of 1 molecule of sulfur dioxide to 1 of oxygen.

That is an excess of oxygen relative to the proportions demanded by the equation.

$$2SO_{2( g)} + O_{2(g)} \rightleftharpoons 2SO_{3( g)} \ \Delta H=-196\text{kJ/mol}$$

According to **Le Chatelier's Principle**, increasing the concentration of oxygen in the mixture causes the position of
equilibrium to shift towards the right. Since the oxygen comes from the air, this is a very cheap way of increasing the conversion of sulfur dioxide into sulfur trioxide.

Why not use an even higher proportion of oxygen? This is easy to see if you take an extreme case. Suppose you have a million molecules of oxygen to every molecule of sulfur dioxide. The equilibrium is going to be tipped very strongly towards sulfur trioxide - virtually every molecule of sulfur dioxide will be converted into sulfur trioxide. However, you aren't going to produce much sulfur trioxide every day. The vast majority of what you are passing over the catalyst is oxygen which has nothing to react with.

By increasing the proportion of oxygen you can increase the percentage of the sulfur dioxide converted, but at the same time decrease the total amount of sulfur trioxide made each day. The 1:1 mixture results in the best possible overall yield of sulfur trioxide.

### Temperature

**Equilibrium considerations:** You need to shift the position of the equilibrium as far as possible to the right in order to produce the maximum possible amount of sulfur trioxide in the equilibrium mixture. The forward reaction (the production of sulfur trioxide) is exothermic.

\[
2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H = -196\text{ kJ/mol}
\]

According to Le Chatelier's Principle, this will be favored if you lower the temperature. The system will respond by moving the position of equilibrium to counteract this - in other words by producing more heat. To get as much sulfur trioxide as possible in the equilibrium mixture, you need as low a temperature as possible. However, 400 - 450°C is not a low temperature!

**Rate considerations:** The lower the temperature you use, the slower the reaction becomes. A manufacturer is trying to produce as much sulfur trioxide as possible per day. It makes no sense to try to achieve an equilibrium mixture which contains a very high proportion of sulfur trioxide if it takes several years for the reaction to reach that equilibrium. You need the gases to reach equilibrium within the very short time that they will be in contact with the catalyst in the reactor.

**The compromise:** 400 - 450°C is a compromise temperature producing a fairly high proportion of sulfur trioxide in the equilibrium mixture, but in a very short time.

### Pressure

**Equilibrium considerations:**

\[
2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H = -196\text{ kJ/mol}
\]

Notice that there are three molecules on the left-hand side of the equation, but only two on the right. According to Le Châtelier's Principle, if you increase the pressure the system will respond by favoring the reaction which produces fewer molecules. That will cause the pressure to fall again. To get as much sulfur trioxide as possible in the equilibrium mixture, you need as high a pressure as possible. High pressures also increase the rate of the reaction. However, the
reaction is done at pressures close to atmospheric pressure!

**Economic considerations:** Even at these relatively low pressures, there is a 99.5% conversion of sulfur dioxide into sulfur trioxide. The very small improvement that you could achieve by increasing the pressure isn't worth the expense of producing those high pressures.

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**Catalyst**

**Equilibrium considerations:** The catalyst has no effect whatsoever on the position of the equilibrium. Adding a catalyst doesn't produce any greater percentage of sulfur trioxide in the equilibrium mixture. Its only function is to speed up the reaction.

**Rate considerations:** In the absence of a catalyst the reaction is so slow that virtually no reaction happens in any sensible time. The catalyst ensures that the reaction is fast enough for a dynamic equilibrium to be set up within the very short time that the gases are actually in the reactor.

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**Contributors and Attributions**

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