

## Oxide des Schwefels

OZ	Monoschwefeloxide $\mathbf{SO}_m$	Di- und Polyschwefeloxide $\mathbf{S}_n\mathbf{O}_m$
+6	$\mathbf{SO}_3$ Schwefeltrioxid	$\mathbf{S}_3\mathbf{O}_9 = (\mathbf{SO}_3)_3$ Trischwefelnonaoxid
Mit Peroxo- gruppen:	$\mathbf{SO}_4$ Schwefeltetraoxid	$(\mathbf{SO}_{3-4})_n$ Polyschwefelperoxide
+4	$\mathbf{SO}_2$ Schwefeldioxid	
+2	$\mathbf{SO}$ Schwefelmonooxid	$\mathbf{S}_2\mathbf{O}_2$ Dischwefeldioxid
+1		$\mathbf{S}_2\mathbf{O}$ Dischwefelmonooxid
< +1		$\mathbf{S}_n\mathbf{O}$ (n = 5 – 10), $\mathbf{S}_n\mathbf{O}_2$ (n = 7) Polyschwefelmono- und dioxide

## Darstellung von Schwefeldioxid SO<sub>2</sub>

Methode	t [°C]	ΔH <sub>f</sub> [kJ]
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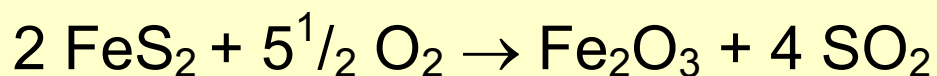
aus Schwefel:



1200 – 1600

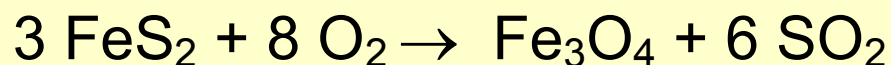
– 297

aus Sulfiden:



650 – 850

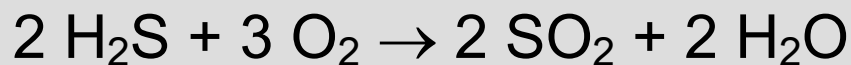
– 1655



650 – 800

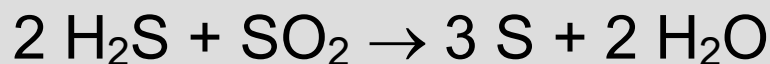
– 2370

aus Schwefelwasserstoff:



1200

– 1037



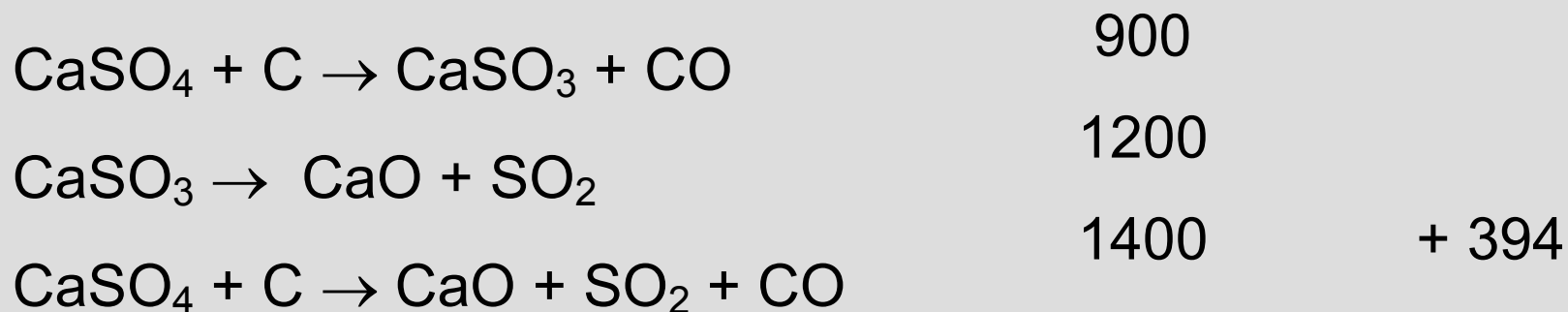
350

– 147

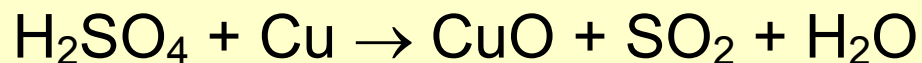
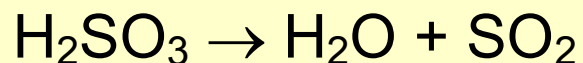
## Darstellung von Schwefeldioxid SO<sub>2</sub>

Methode	t [°C]	ΔH <sub>f</sub> [kJ]
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aus Sulfaten:



aus Säuren:



aus Schwefeltrioxid:



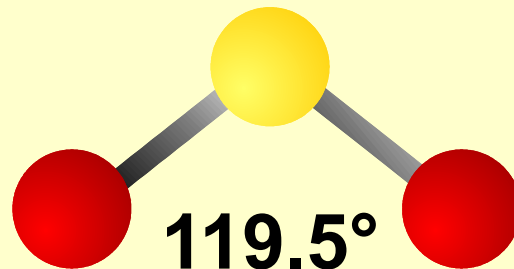
# Eigenschaften von Schwefeldioxid SO<sub>2</sub>

Farbloses, giftiges Gas

nicht brennbar, stechender Geruch

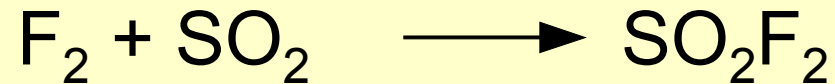
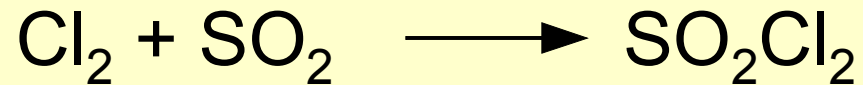
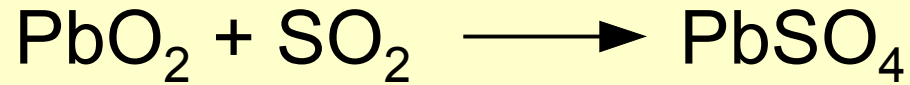
Siedepunkt:  $-10^{\circ}\text{C}$ , Schmelzpunkt:  $-75.5^{\circ}\text{C}$

Sehr gut löslich in Wasser: 1 Liter Wasser löst 40 Liter SO<sub>2</sub>  
(bei  $20^{\circ}\text{C}$ )



# Eigenschaften von Schwefeldioxid SO<sub>2</sub>

## Reduktionsmittel:



# Verwendung von Schwefeldioxid SO<sub>2</sub>

Herstellung von Schwefelsäure

Herstellung schwefelhaltiger Verbindungen

nichtwässriges Lösungsmittel

Reduktionsmittel im Hüttenwesen

Kühlmittel

Desinfektionsmittel (Bier- und Weinfässer)

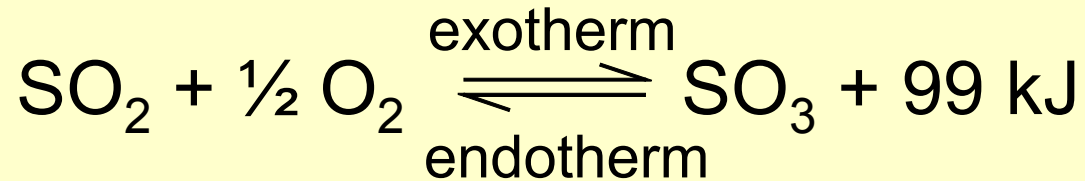
Konservierung von Lebensmitteln („Schwefeln“)

Schädlingsbekämpfungsmittel

(Nagetiere, Kücheninsekten)

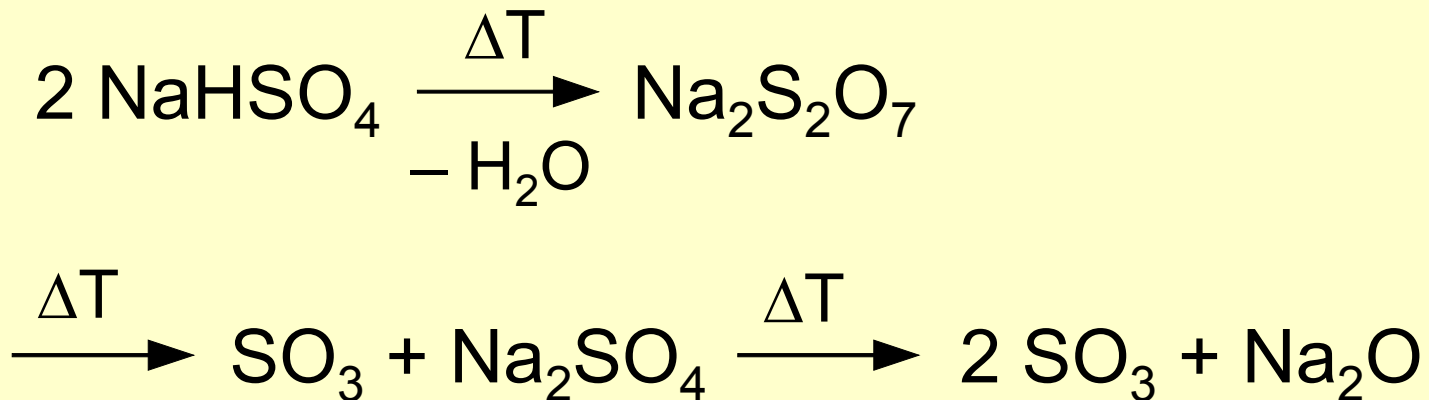


## Darstellung von Schwefeltrioxid SO<sub>3</sub>



Verläuft nur mit Katalysatoren

Im Labor:

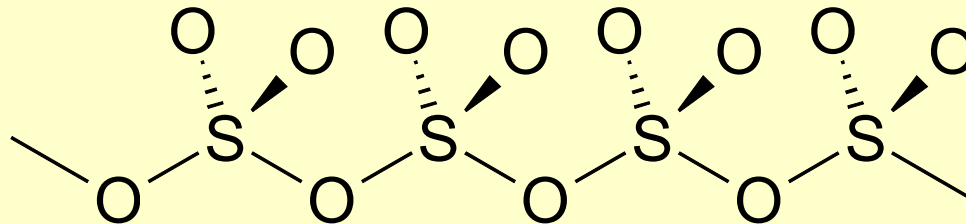
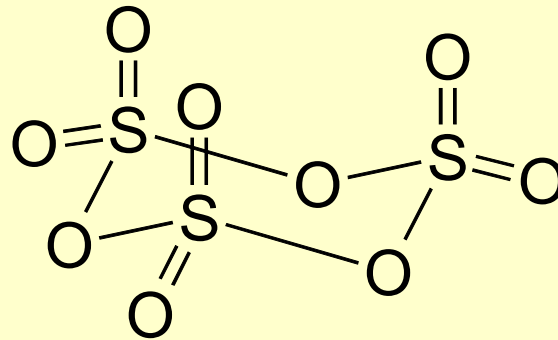
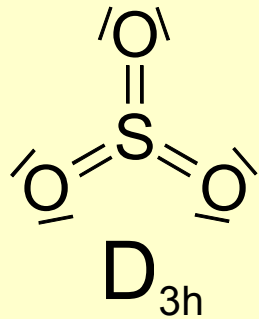


# Eigenschaften von Schwefeltrioxid $\text{SO}_3$

Feststoff in drei Modifikationen

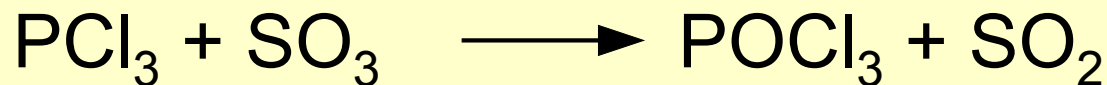
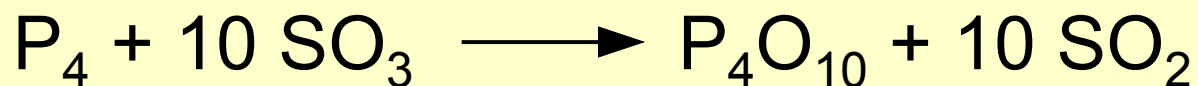
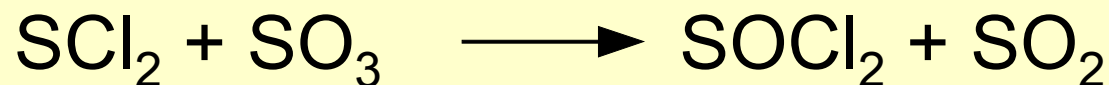
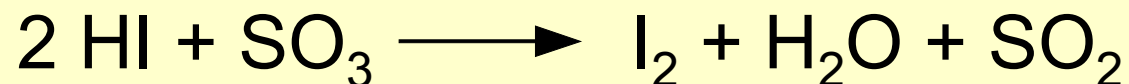
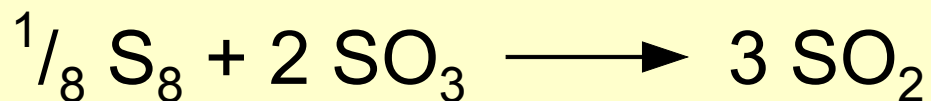
Siedepunkt:  $45^\circ\text{C}$

Schmelzpunkt:  $\alpha$ -Form  $62^\circ\text{C}$ ,  $\beta$ -Form  $32^\circ\text{C}$ ,  $\gamma$ -Form  $17^\circ\text{C}$



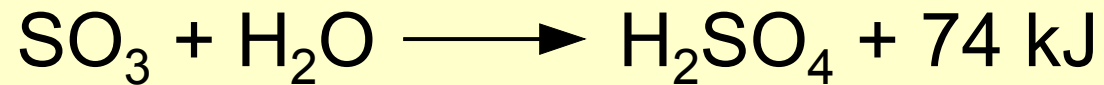
# Eigenschaften von Schwefeltrioxid SO<sub>3</sub>

## Oxidationsmittel



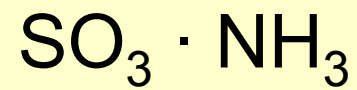
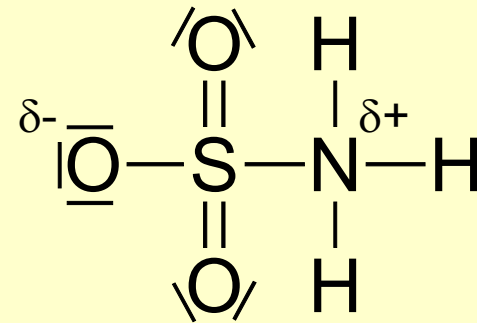
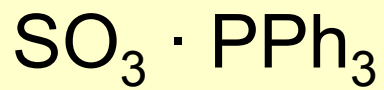
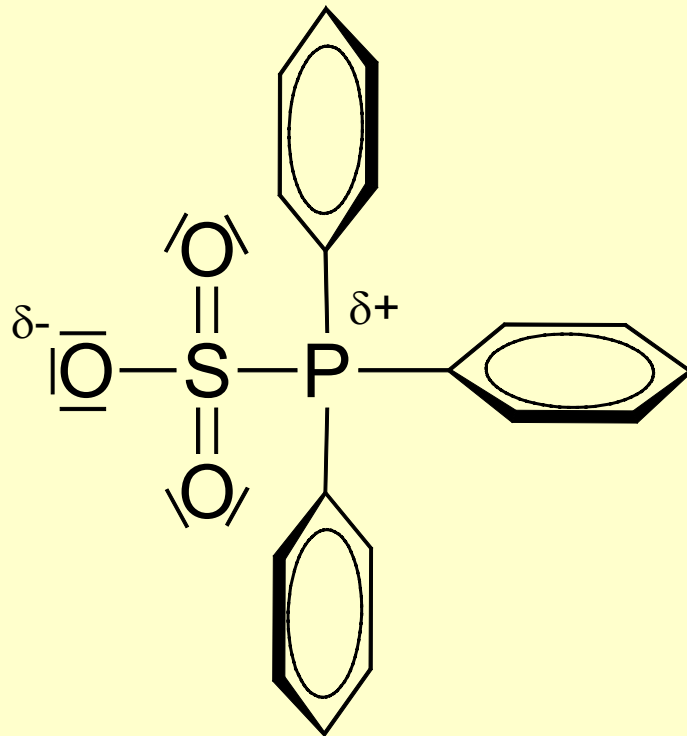
## Eigenschaften von Schwefeltrioxid $\text{SO}_3$

Mit Wasser entsteht Schwefelsäure:



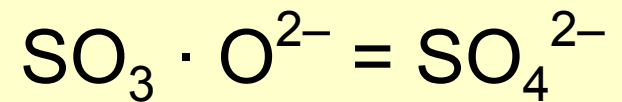
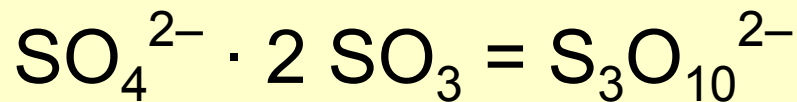
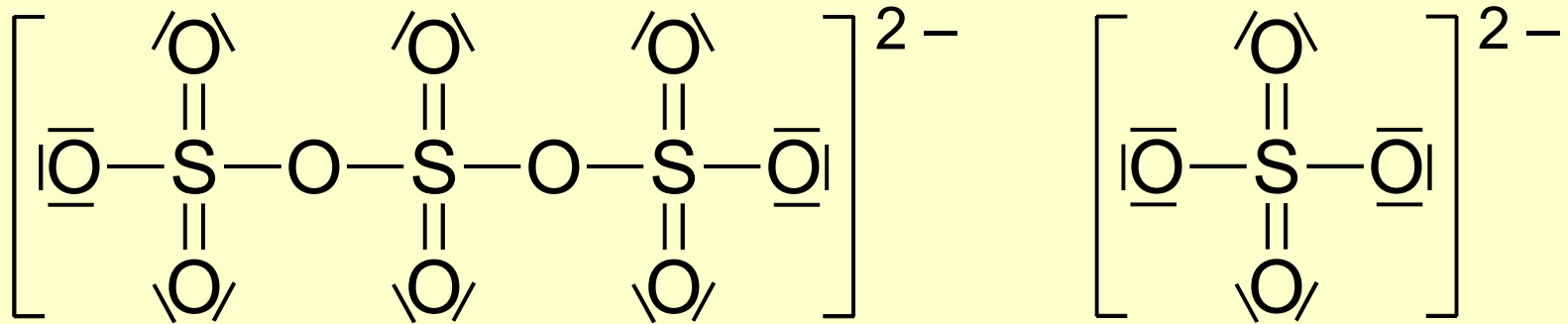
# Eigenschaften von Schwefeltrioxid $\text{SO}_3$

Starke Lewissäure:



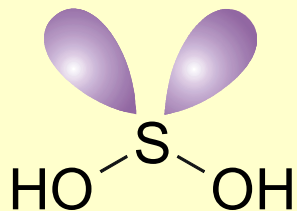
# Eigenschaften von Schwefeltrioxid $\text{SO}_3$

Starke Lewissäure:



# Sauerstoffsäuren - Monoschwefelsäuren

+ 2 H<sub>2</sub>SO<sub>2</sub>



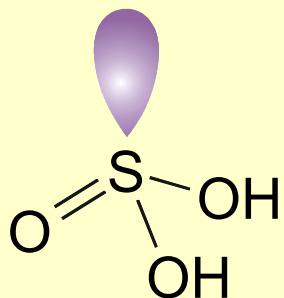
Sulfoxylsäure

Sulfoxylate

Schwefel(II)säure

Sulfate(II)

+ 4 H<sub>2</sub>SO<sub>3</sub>



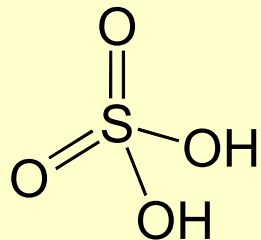
Schweflige Säure

Sulfite

Schwefel(IV)säure

Sulfate(IV)

+ 6 H<sub>2</sub>SO<sub>4</sub>



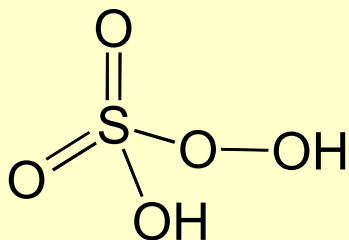
Schwefelsäure

Sulfate

Schwefel(VI)säure

Sulfate(VI)

+ 6 H<sub>2</sub>SO<sub>5</sub>



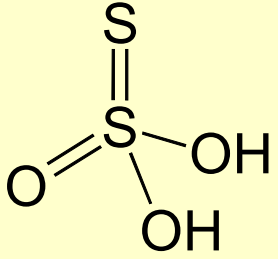
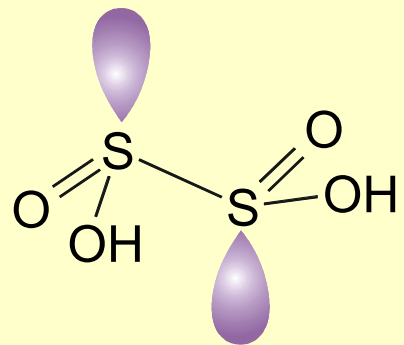
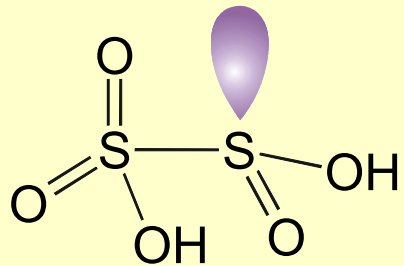
Peroxo-

Peroxo-

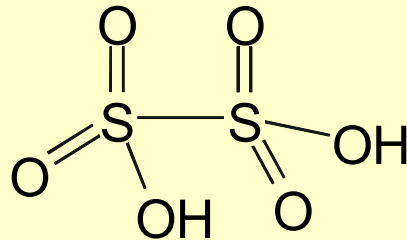
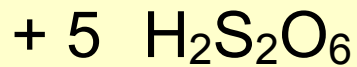
schwefel(VI)säure

sulfate(VI)

# Sauerstoffsäuren - Dischwefelsäuren

+ 2	$\text{H}_2\text{S}_2\text{O}_3$		Thioschwefelsäure Dischwefel(II)säure	Thiosulfate Disulfate(II)
+ 3	$\text{H}_2\text{S}_2\text{O}_4$		Dithionige Säure Dischwefel(III)säure	Dithionite Disulfate(III)
+ 4	$\text{H}_2\text{S}_2\text{O}_5$		Dischweflige Säure Dischwefel(IV)säure	Disulfite Disulfate(IV)

# Sauerstoffsäuren - Dischwefelsäuren

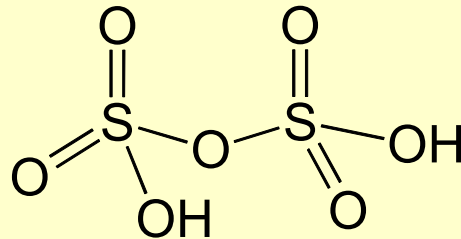
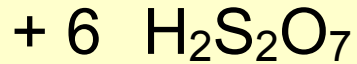


Dithionsäure

Dithionate

Dischwefel(V)säure

Disulfate(V)

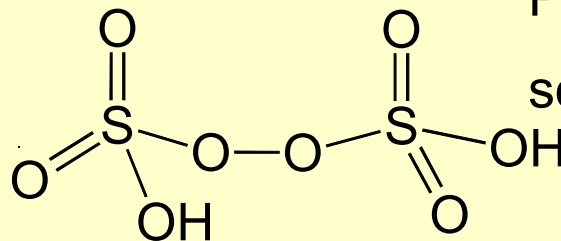
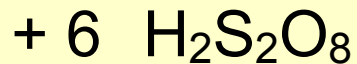


Dischwefelsäure

Disulfate

Dischwefel(VI)säure

Disulfate(VI)



Peroxodi-

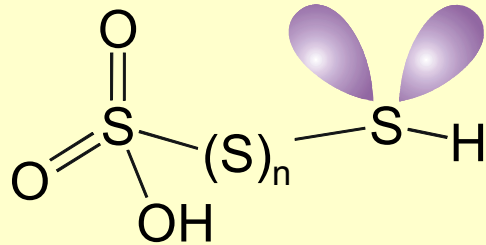
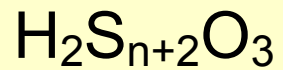
Peroxodi-

schwefel(VI)säure

sulfate(VI)

# Sauerstoffsäuren - Polyschwefelsäuren

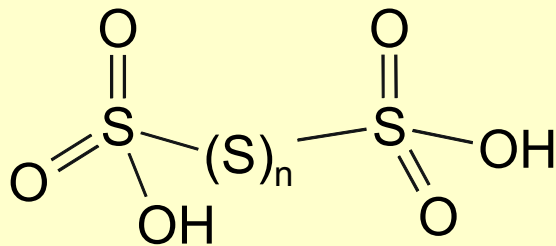
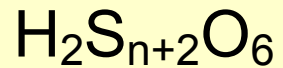
OZ: +5, 0, -2



Polysulfan-  
monosul-  
fonsäure

Polysulfanmono-  
sulfonate

OZ: +5, 0

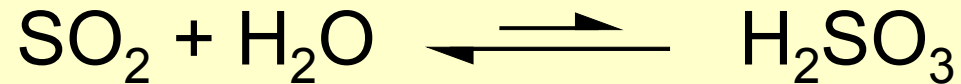


Polythion-  
säure

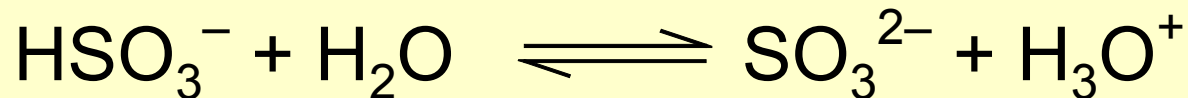
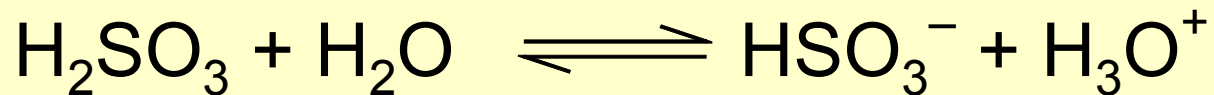
Polythionat

## Schweflige Säure $\text{H}_2\text{SO}_3$

Darstellung:



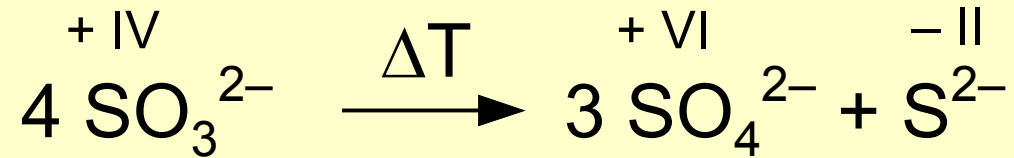
In wässriger Lösung erfolgt nahezu vollständige Dissoziation:



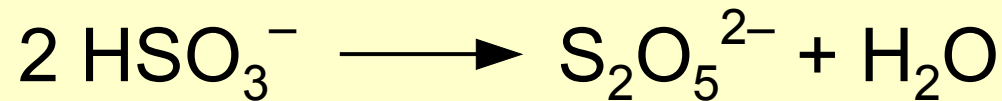
Hydrogensulfite und Sulfite

## Schweflige Säure $\text{H}_2\text{SO}_3$

Sulfite disproportionieren beim Erhitzen:

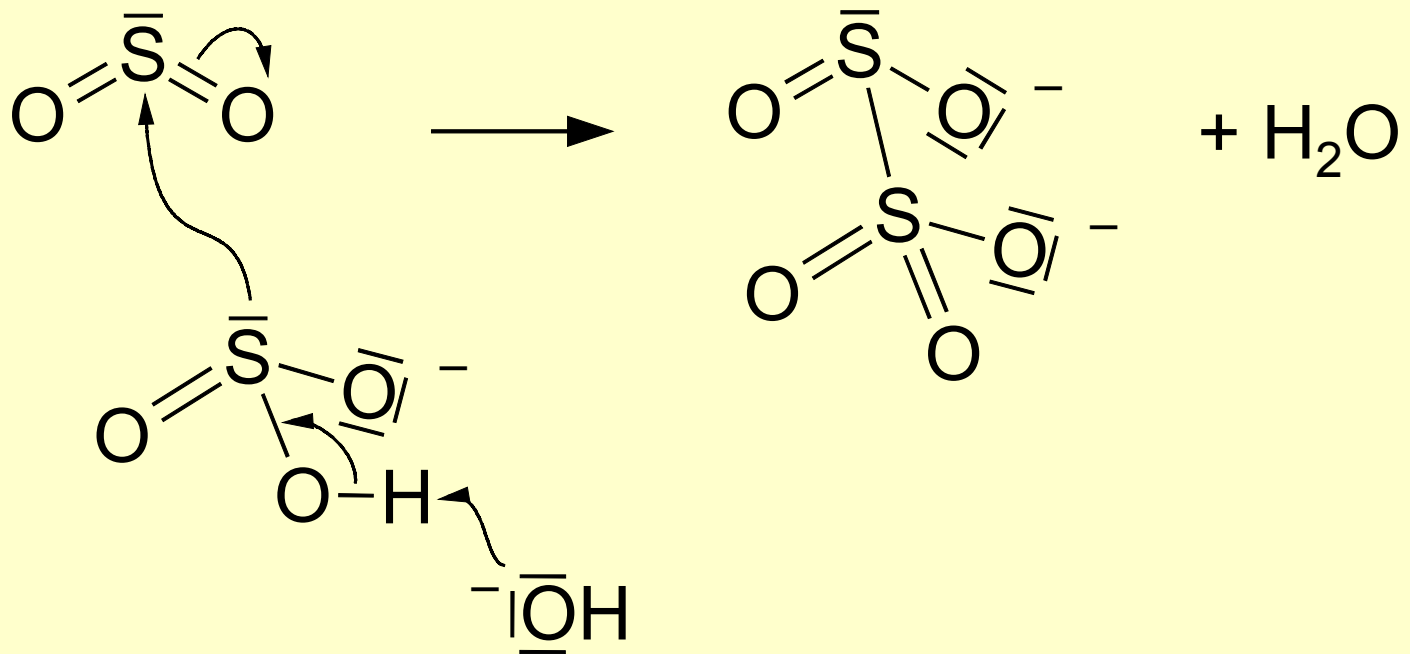
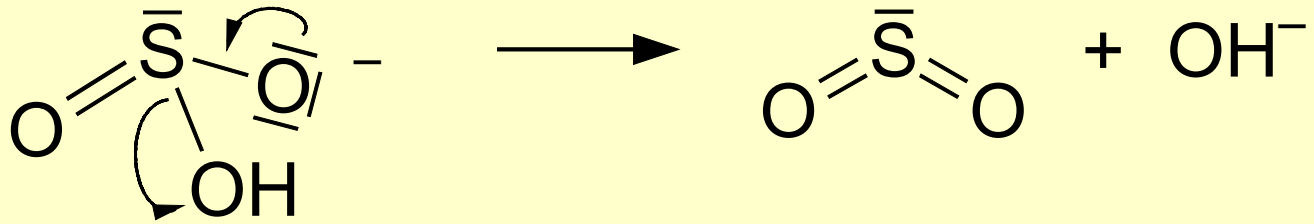


In konzentrierter Lösung erfolgt Kondensation:



Disulfit (Pyrosulfit)

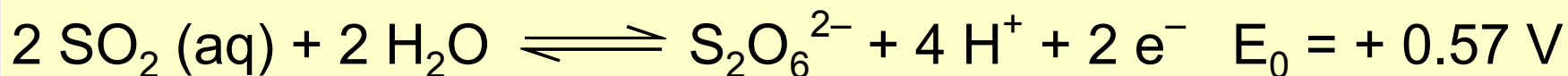
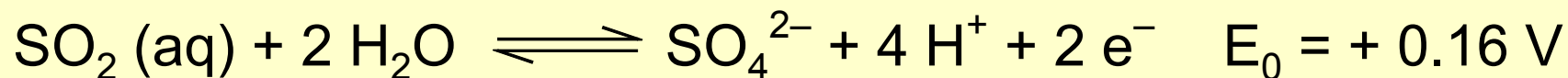
# Bildung von Disulfit



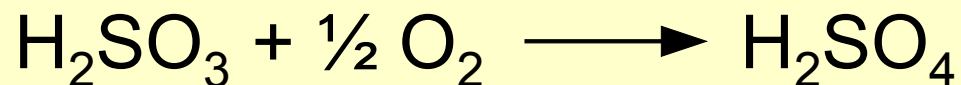
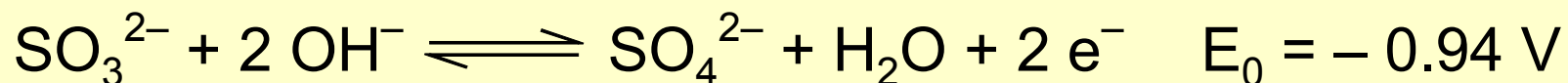
## Schweflige Säure - Eigenschaften

Mäßig starke Reduktionsmittel:

saure Lösung

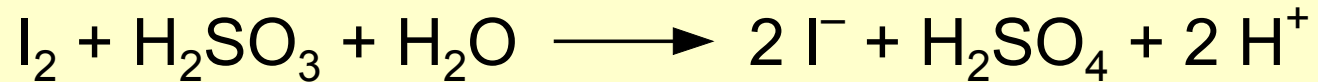


alkalische Lösung

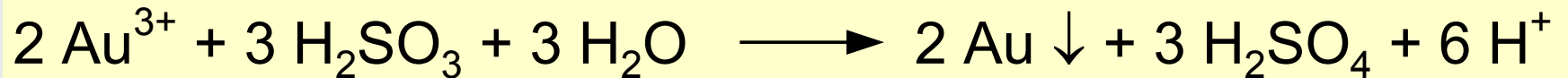


## Schweflige Säure - Reduktionswirkung

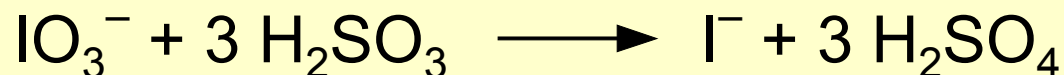
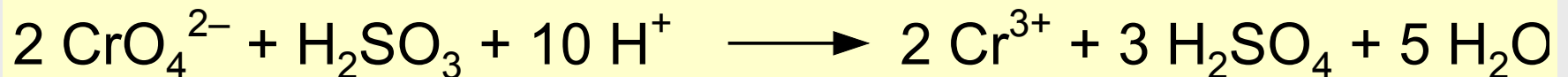
Reduktion von Halogenen:



Reduktion von Metallkationen:

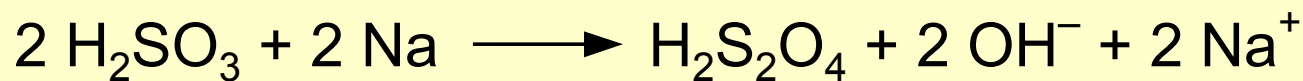
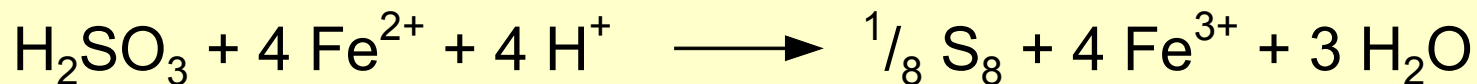


Reduktion von Metall- und Nichtmetalloxiden:

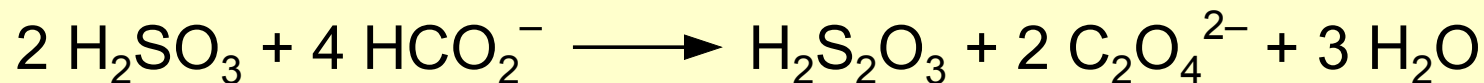
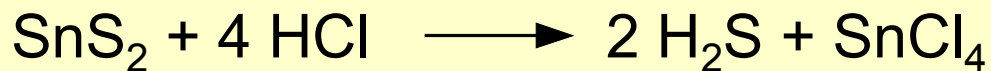
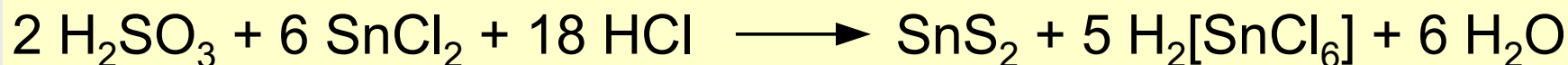
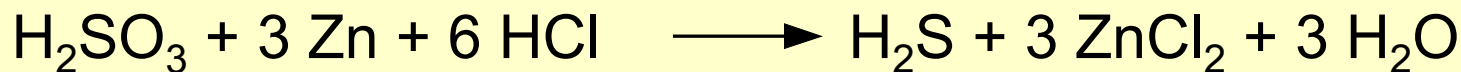


## Reduktion von Schwefliger Säure

Gelingt nur mit starken Reduktionsmitteln:

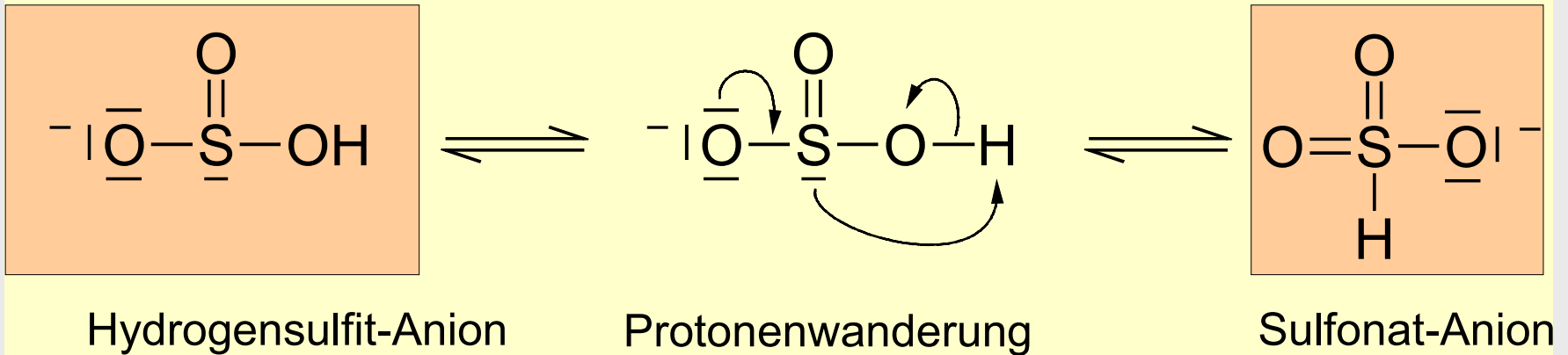
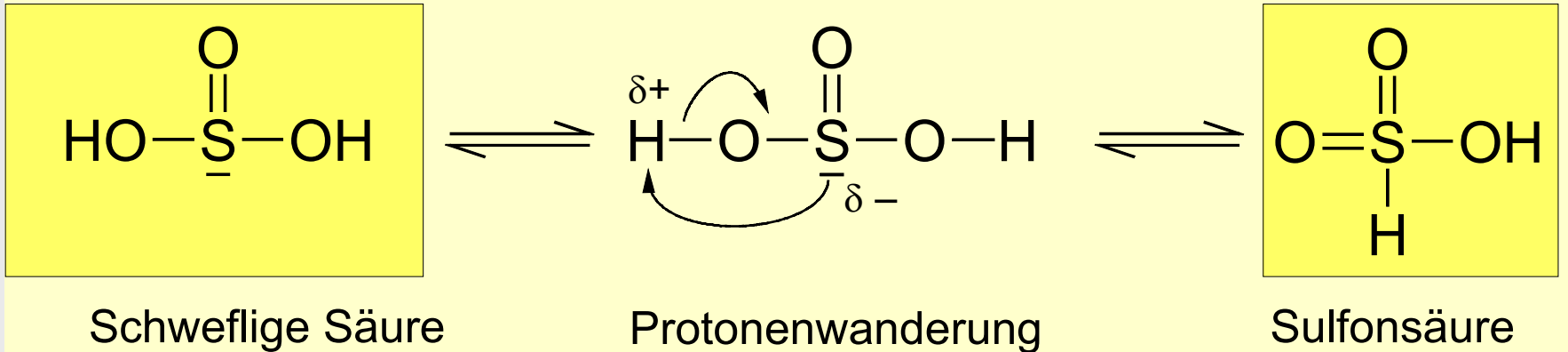


Dithionige Säure

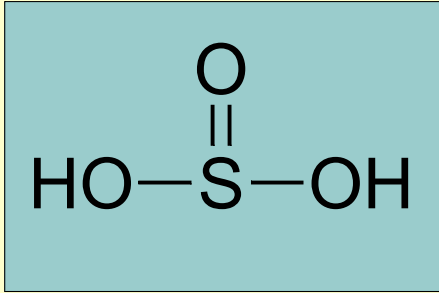


Thioschwefelsäure

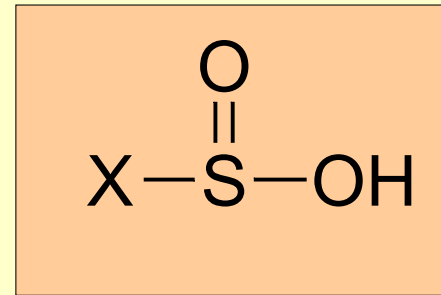
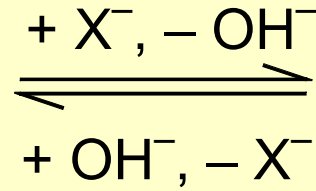
# Derivate der Schwefligen Säure



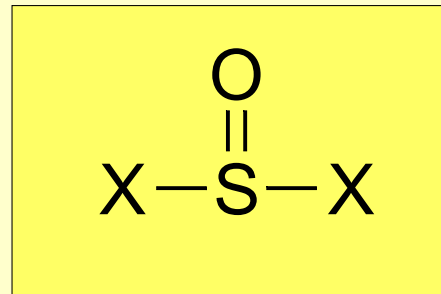
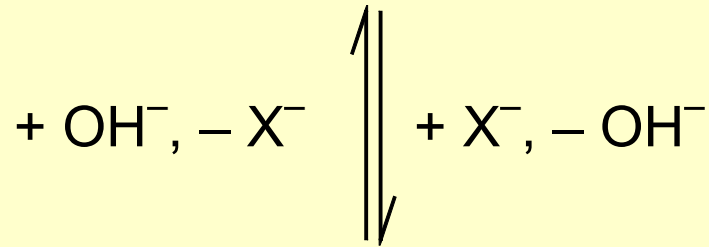
# Derivate der Schwefligen Säure



Schweflige Säure



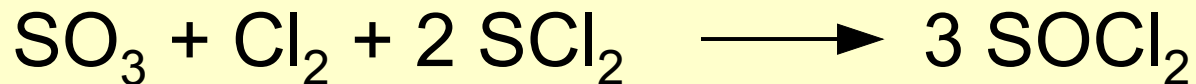
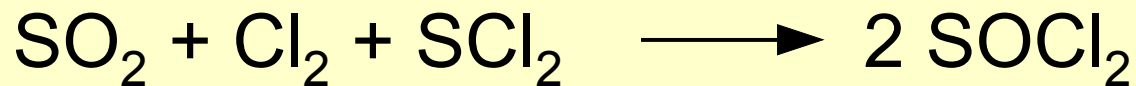
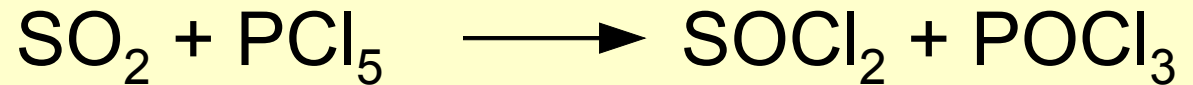
Sulfinsäure



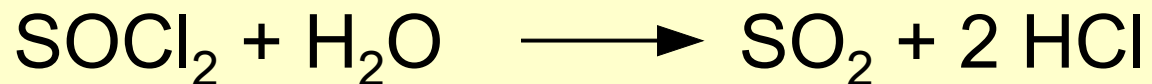
Thionylverbindung

# Thionylchlorid

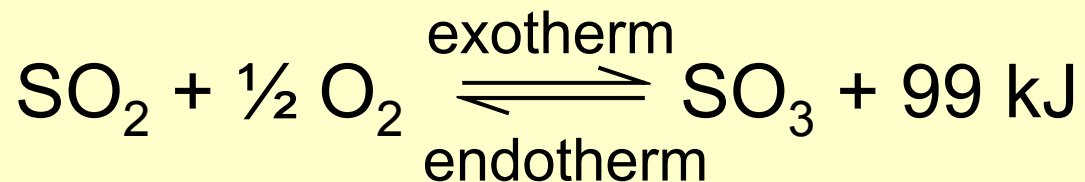
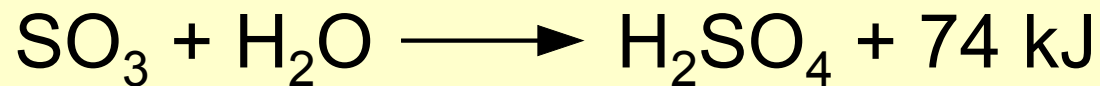
Darstellung:



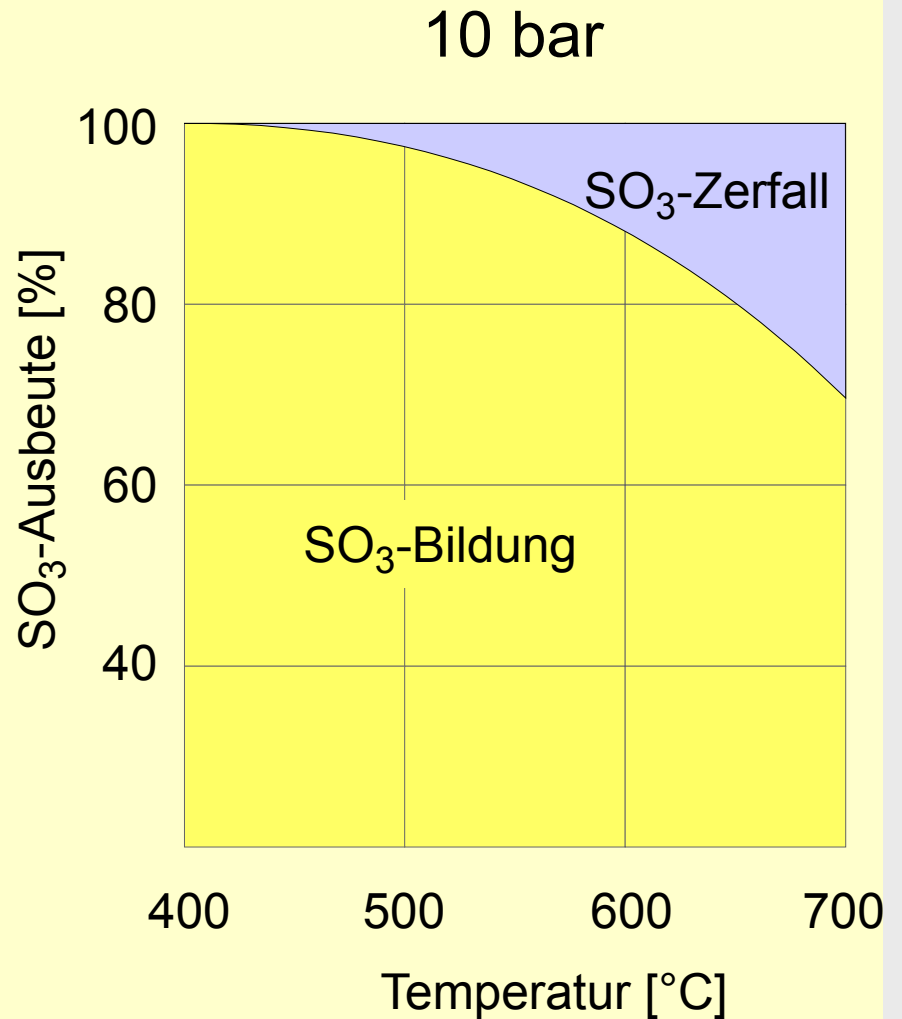
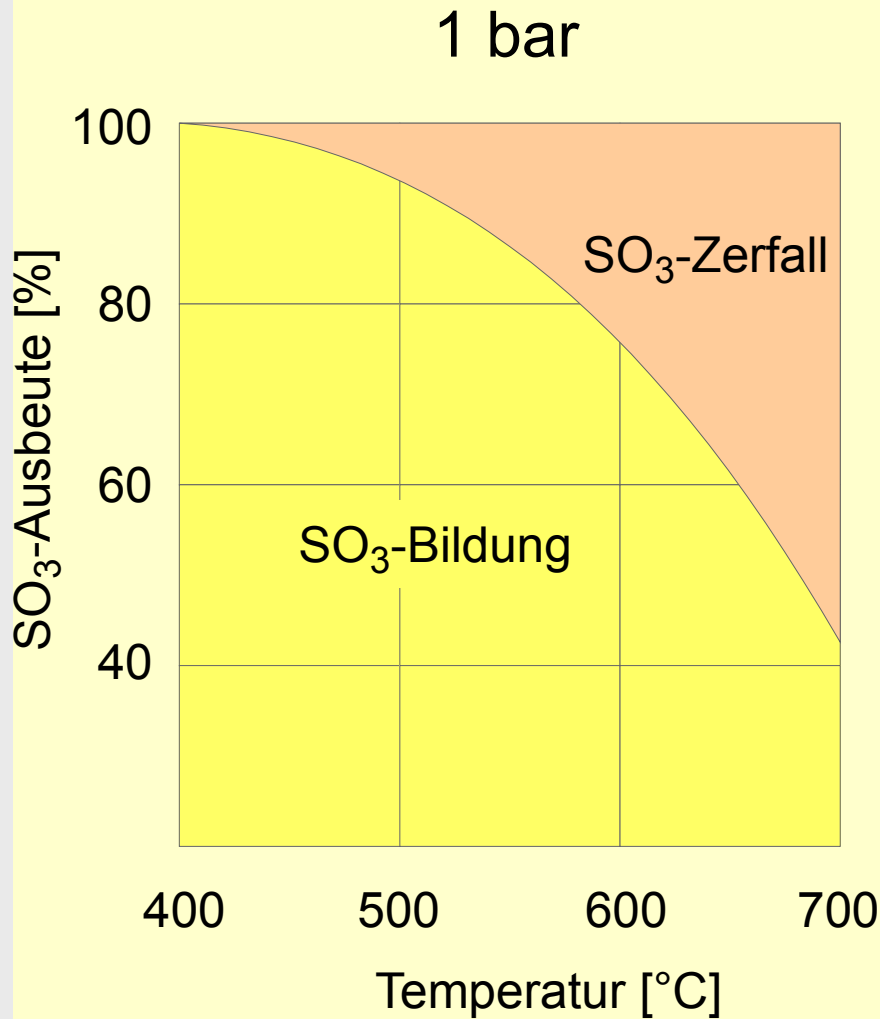
Große Affinität zu Wasser:



## Schwefelsäure $\text{H}_2\text{SO}_4$

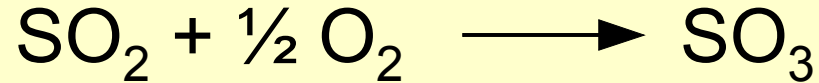
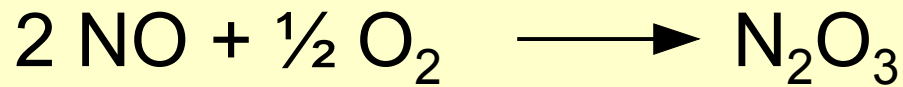
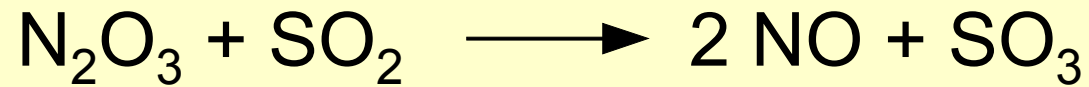


# Temperatur- und Druckabhängigkeit der SO<sub>3</sub>-Ausbeute

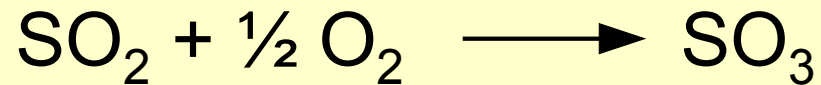
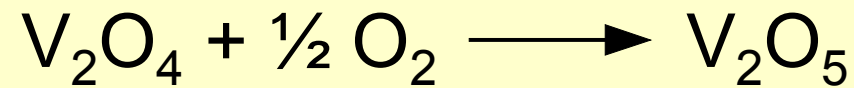
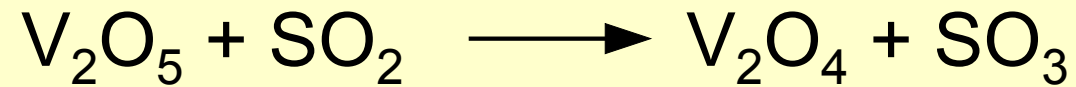


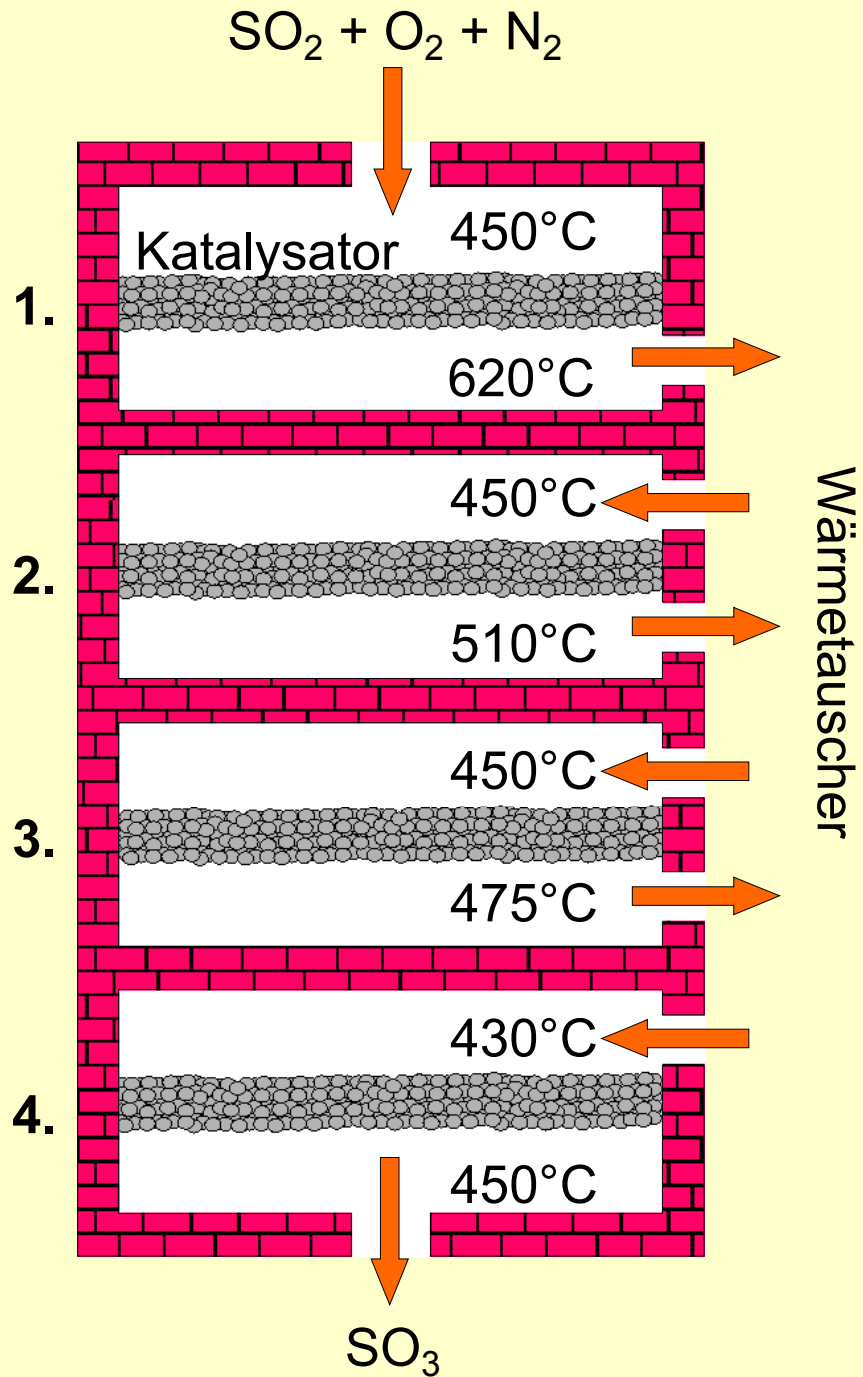
10 Vol-% SO<sub>2</sub>, 10.9 Vol-% O<sub>2</sub>, 79.9 Vol-% N<sub>2</sub>

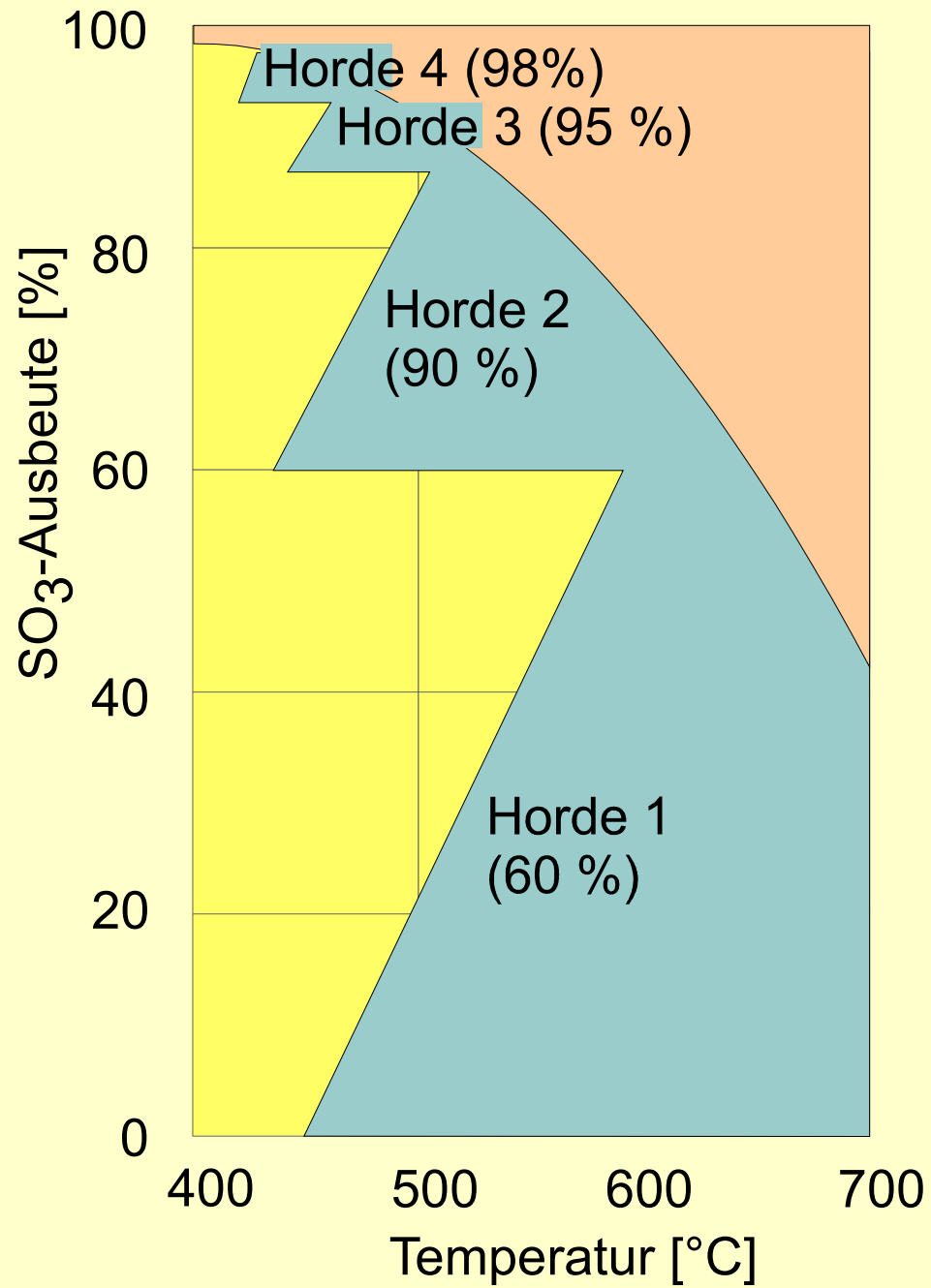
## Das Bleikammerverfahren



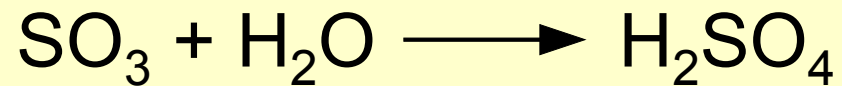
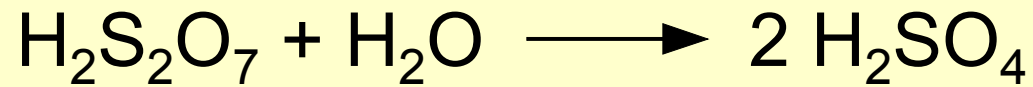
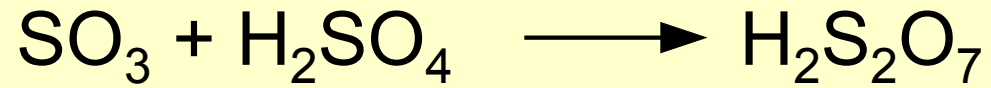
# Das Kontaktverfahren



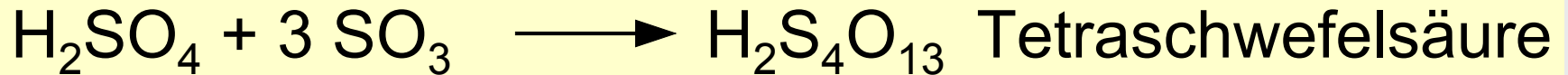
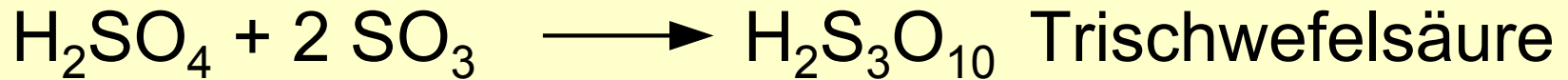
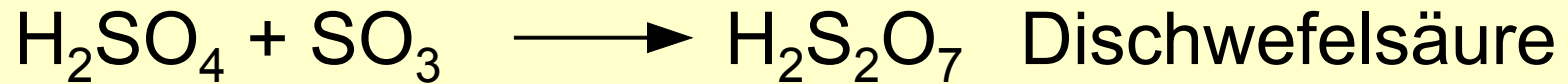


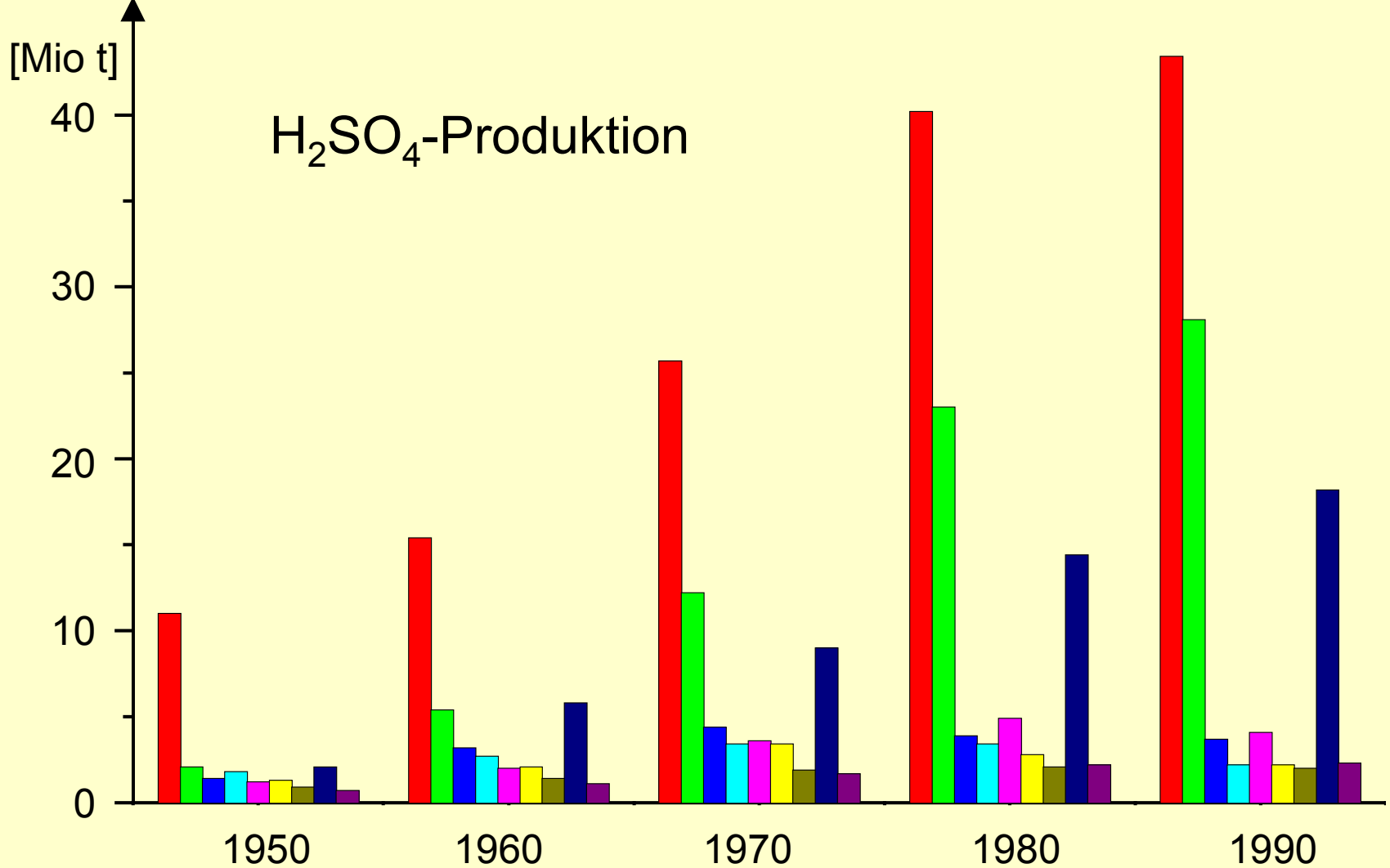


## Gewinnung von Schwefelsäure



## Schwefeltrioxid und Schwefelsäure





# H<sub>2</sub>SO<sub>4</sub>-Produktion

[Mio t]

100  
90  
80  
70  
60  
50  
40  
30  
20  
10  
0

Welt

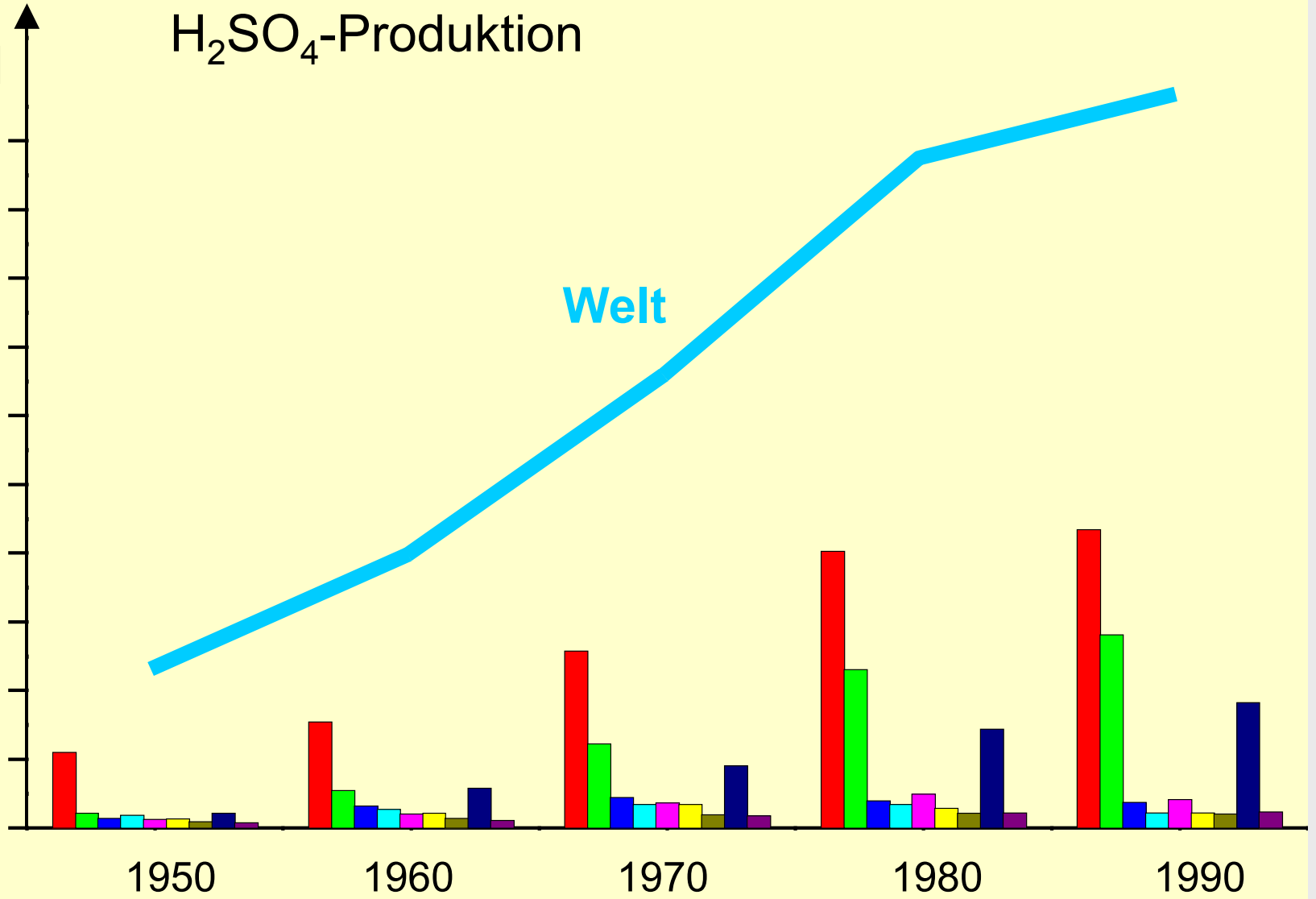
1950

1960

1970

1980

1990



# Eigenschaften der Schwefelsäure

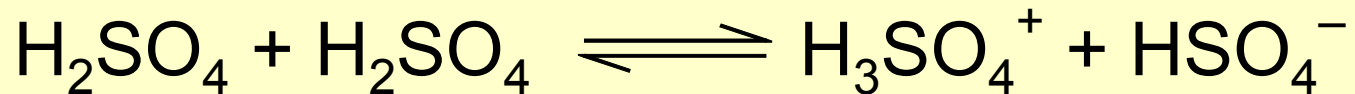
Wasserfreie Schwefelsäure: farblose, ölige, schwere Flüssigkeit ( $d = 1.83 \text{ g/cm}^3$ )

Schmelzpunkt:  $10.4 \text{ }^\circ\text{C}$ , (98%-ige nur noch  $3^\circ\text{C}$ )

große Affinität zu Wasser

große Oxidationskraft

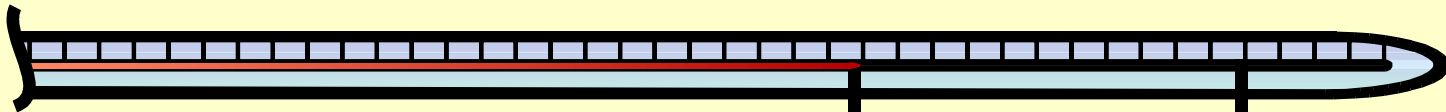
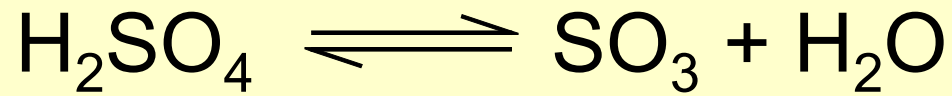
Eigendissoziation:



# Eigenschaften der Schwefelsäure

tiefere  
Temperaturen

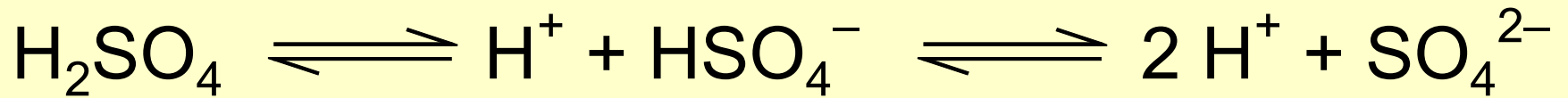
hohe  
Temperaturen



338°C

450°C

# Eigenschaften der Schwefelsäure

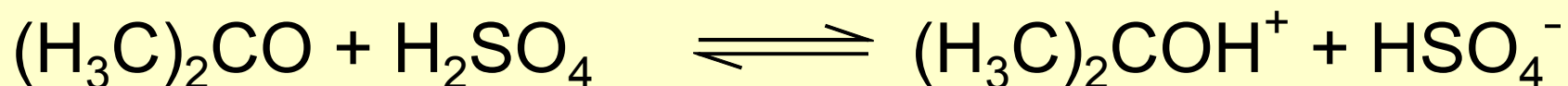
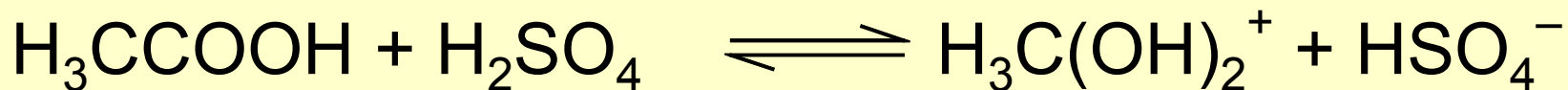
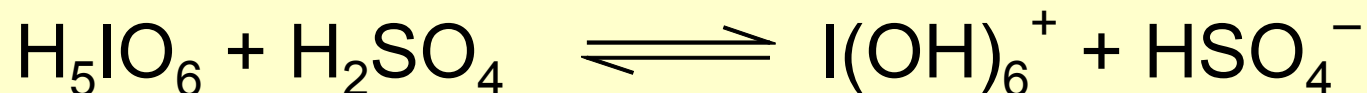
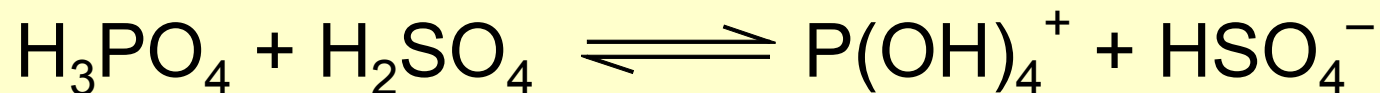
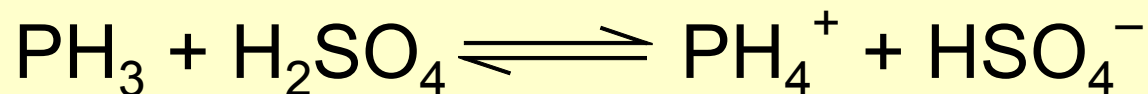
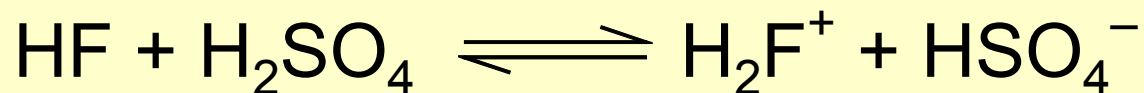


1. Dissoziation

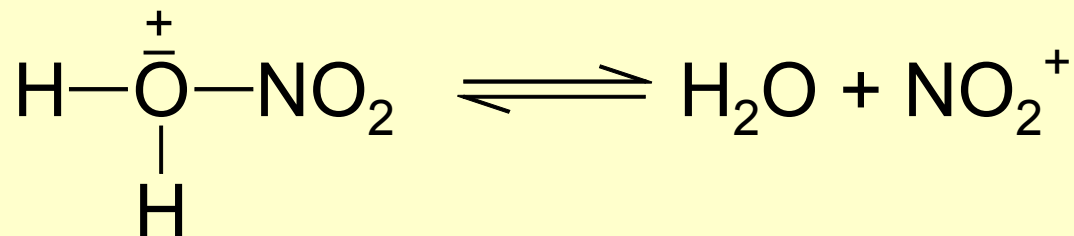
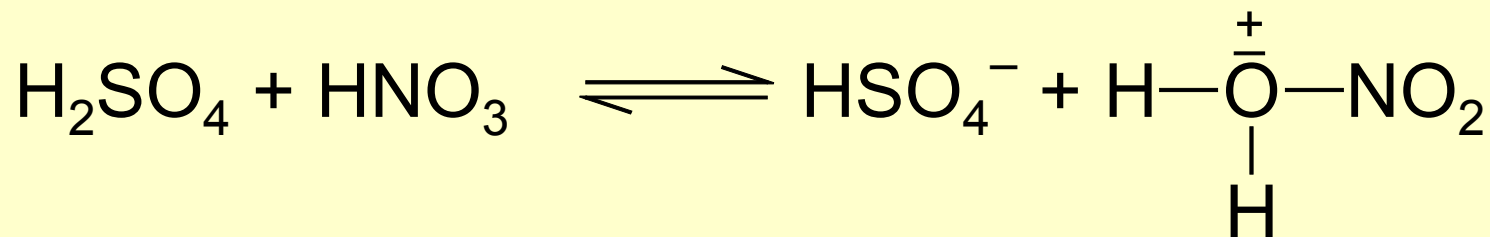
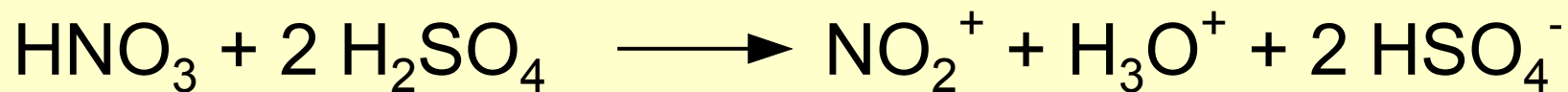
2. Dissoziation

Hydrogensulfate und Sulfate

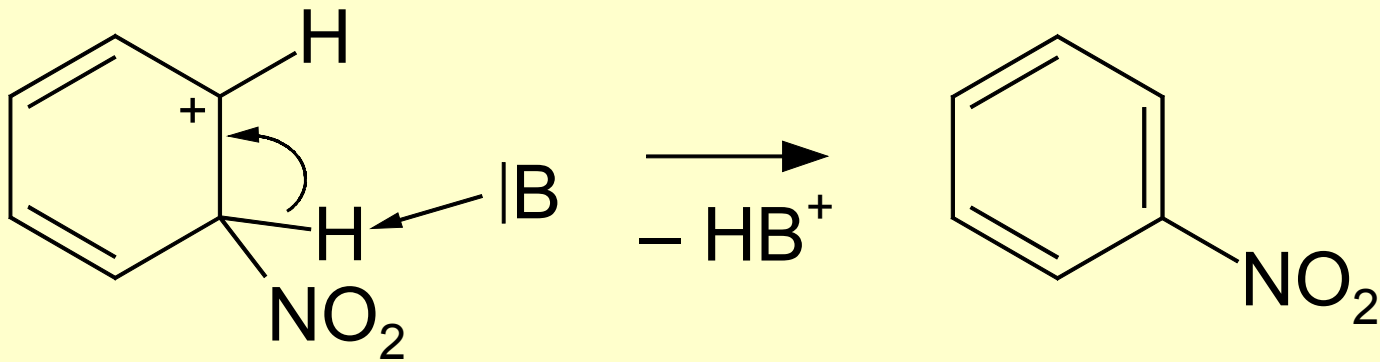
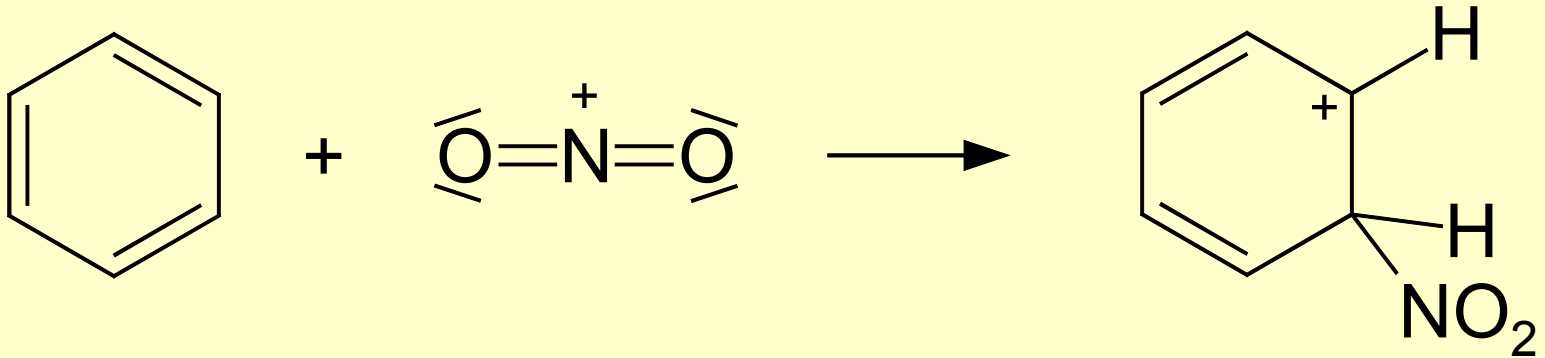
## Eigenschaften der Schwefelsäure



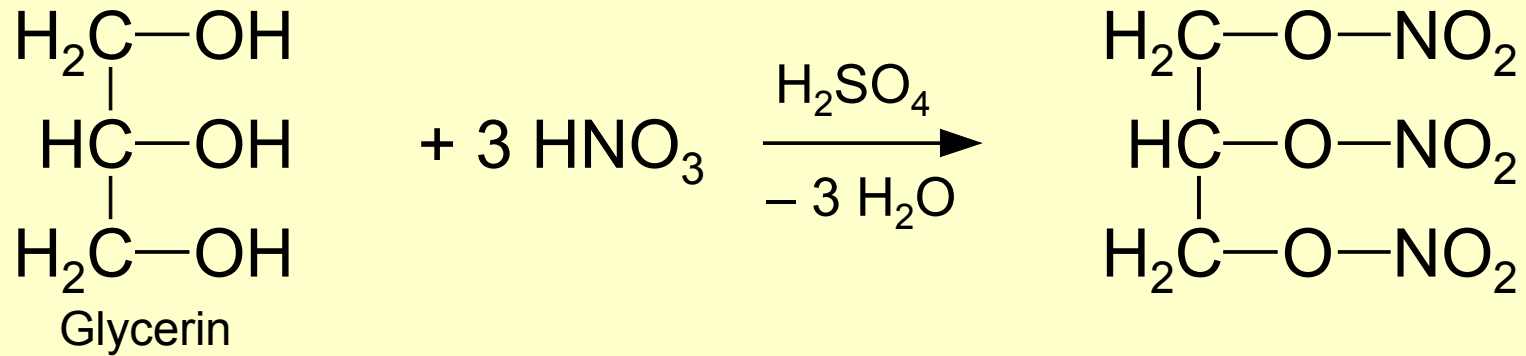
## Nitriersäure



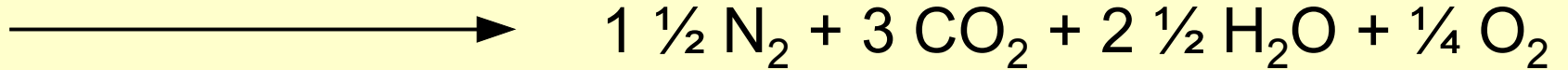
# Nitriersäure



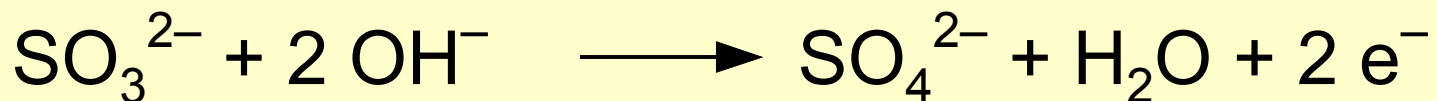
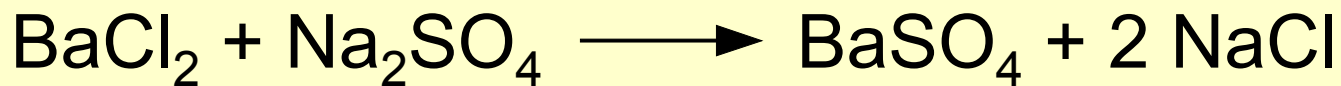
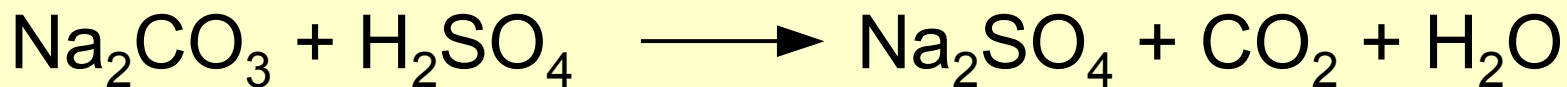
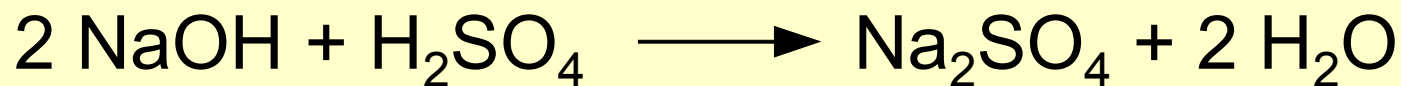
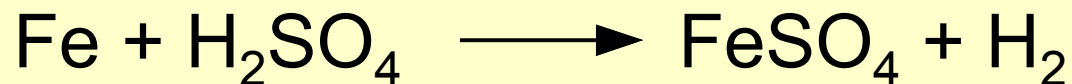
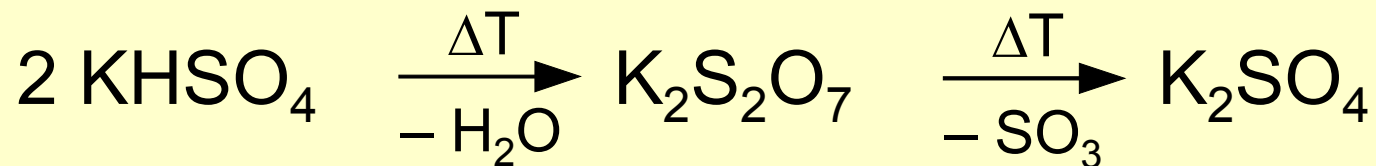
# Nitriersäure



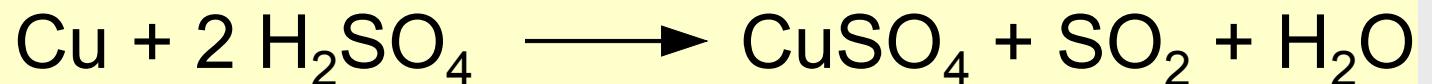
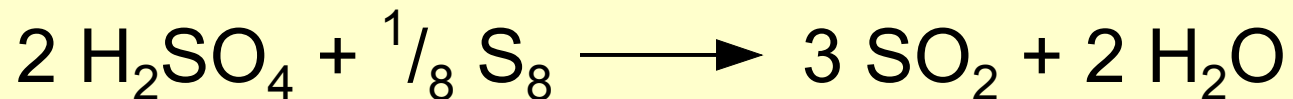
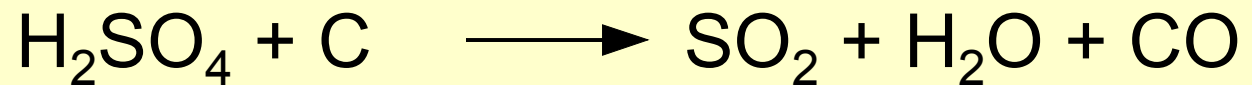
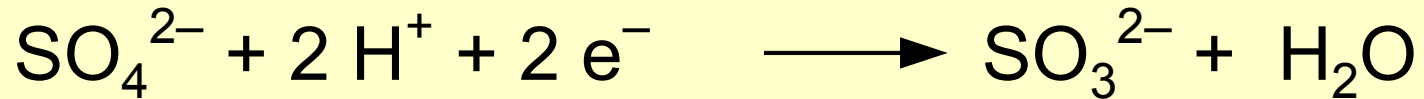
Wärme oder Schlag



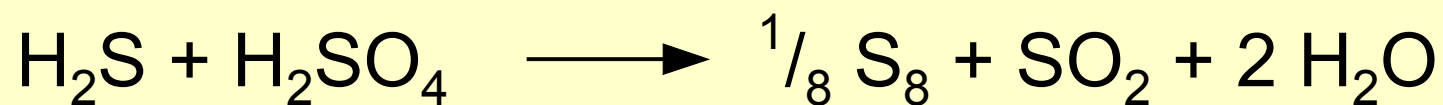
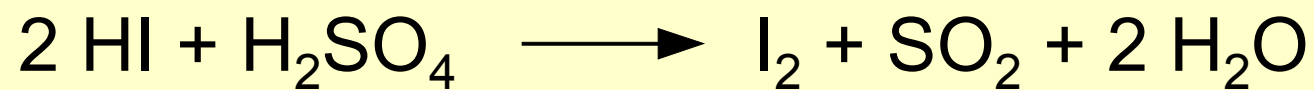
## Sulfate



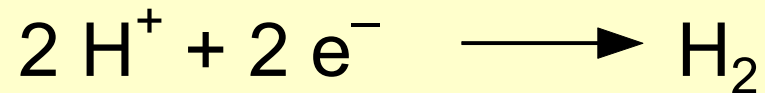
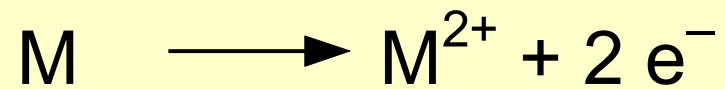
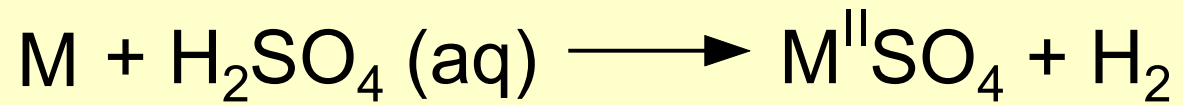
## Oxidationswirkung



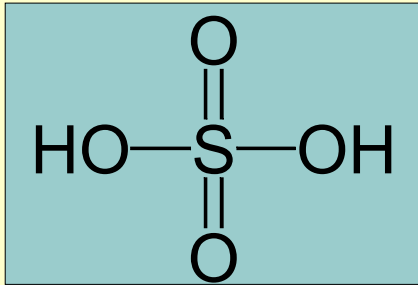
## Oxidationswirkung



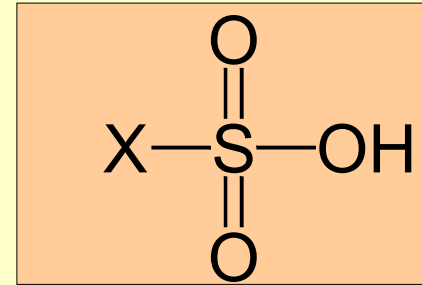
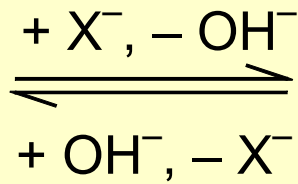
## Verdünnte Schwefelsäure



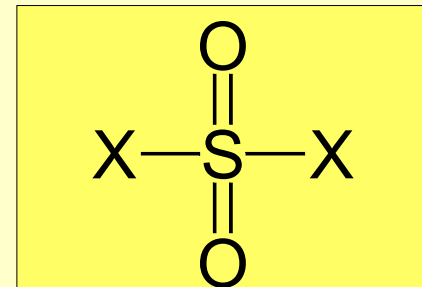
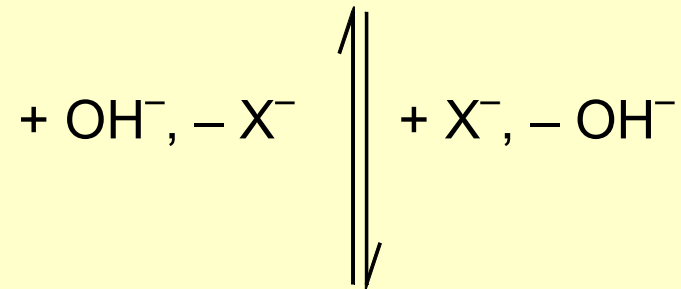
# Derivate der Schwefelsäure



Schwefelsäure

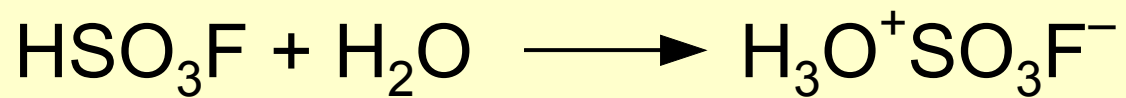
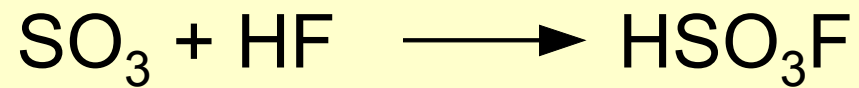


Sulfonsäure

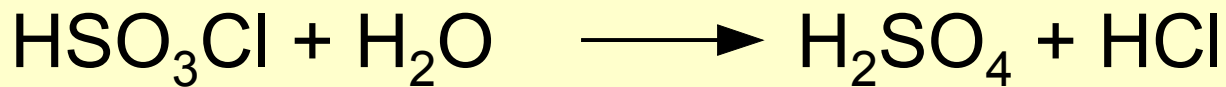
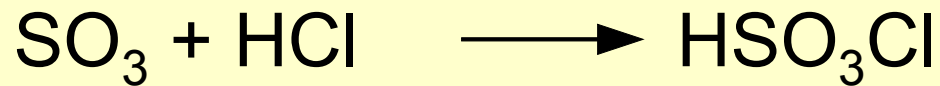
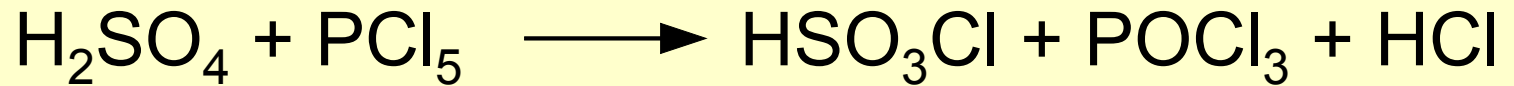


Sulfurylverbindung

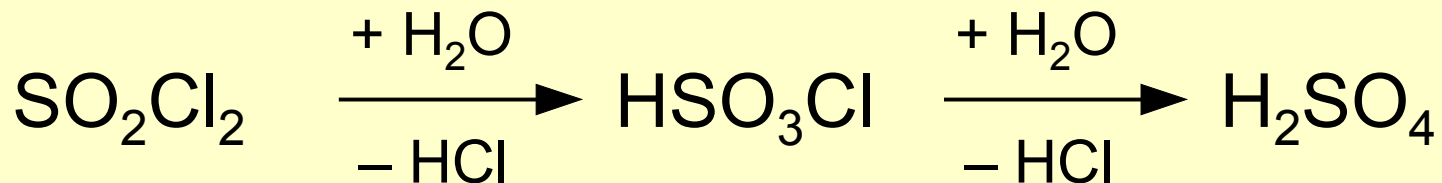
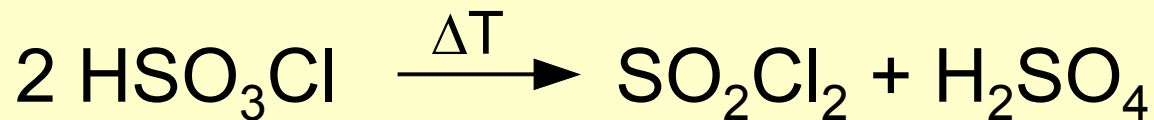
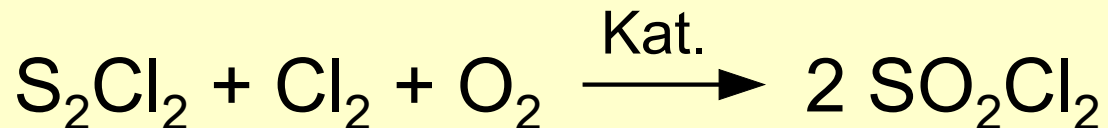
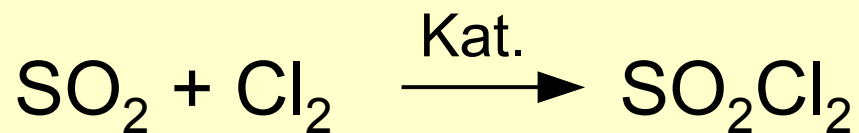
# Fluorsulfonsäure



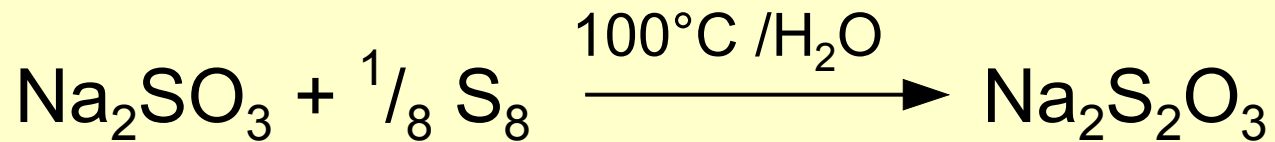
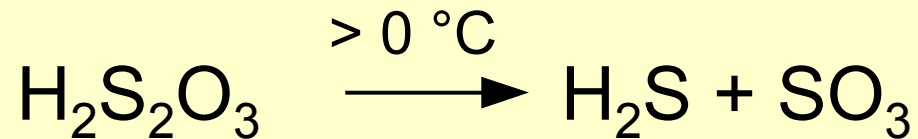
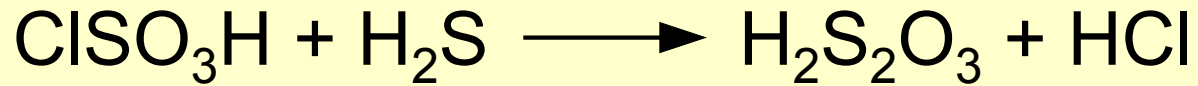
# Chlorsulfonsäure



## Sulfurylchlorid $\text{SO}_2\text{Cl}_2$

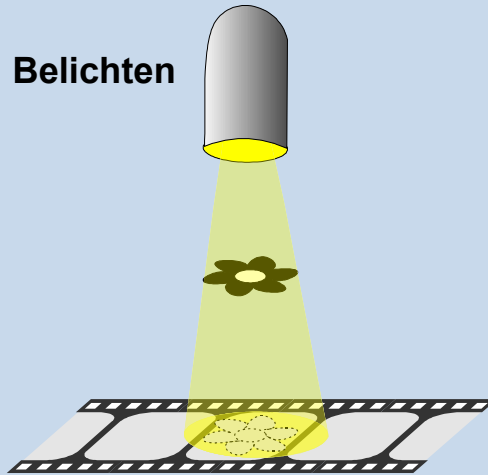


## Thioschwefelsäure - Thiosulfate



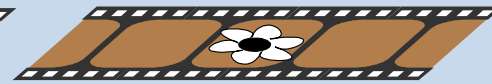
# Der fotografische Prozess

**Belichten**



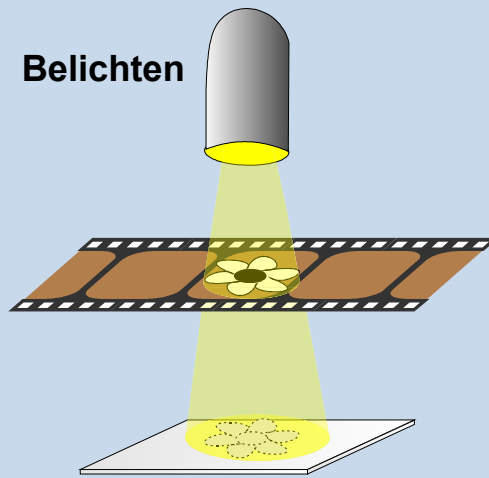
lichtempfindlicher Film

**Entwickeln und Fixieren**



Negativ-Film

**Belichten**



lichtempfindliches Papier

**Entwickeln und Fixieren**

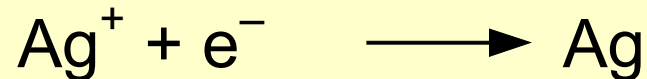
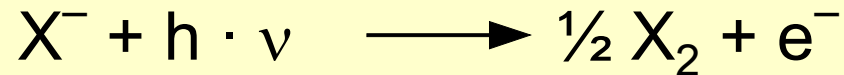
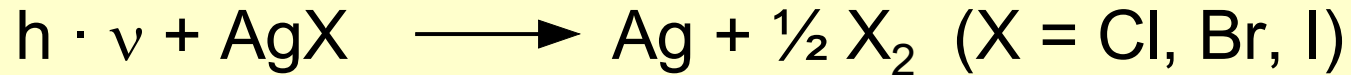


# Der fotografische Prozess

- Erzeugung einer lichtempfindlichen Schicht auf einem Trägermaterial
- Belichtung der lichtempfindlichen Schicht zum Erhalten einer latenten Abbildung
- Entwicklung der latenten Abbildung zum Negativ
- Fixierung des Negativs
- Belichtung des Negativs zum Positiv

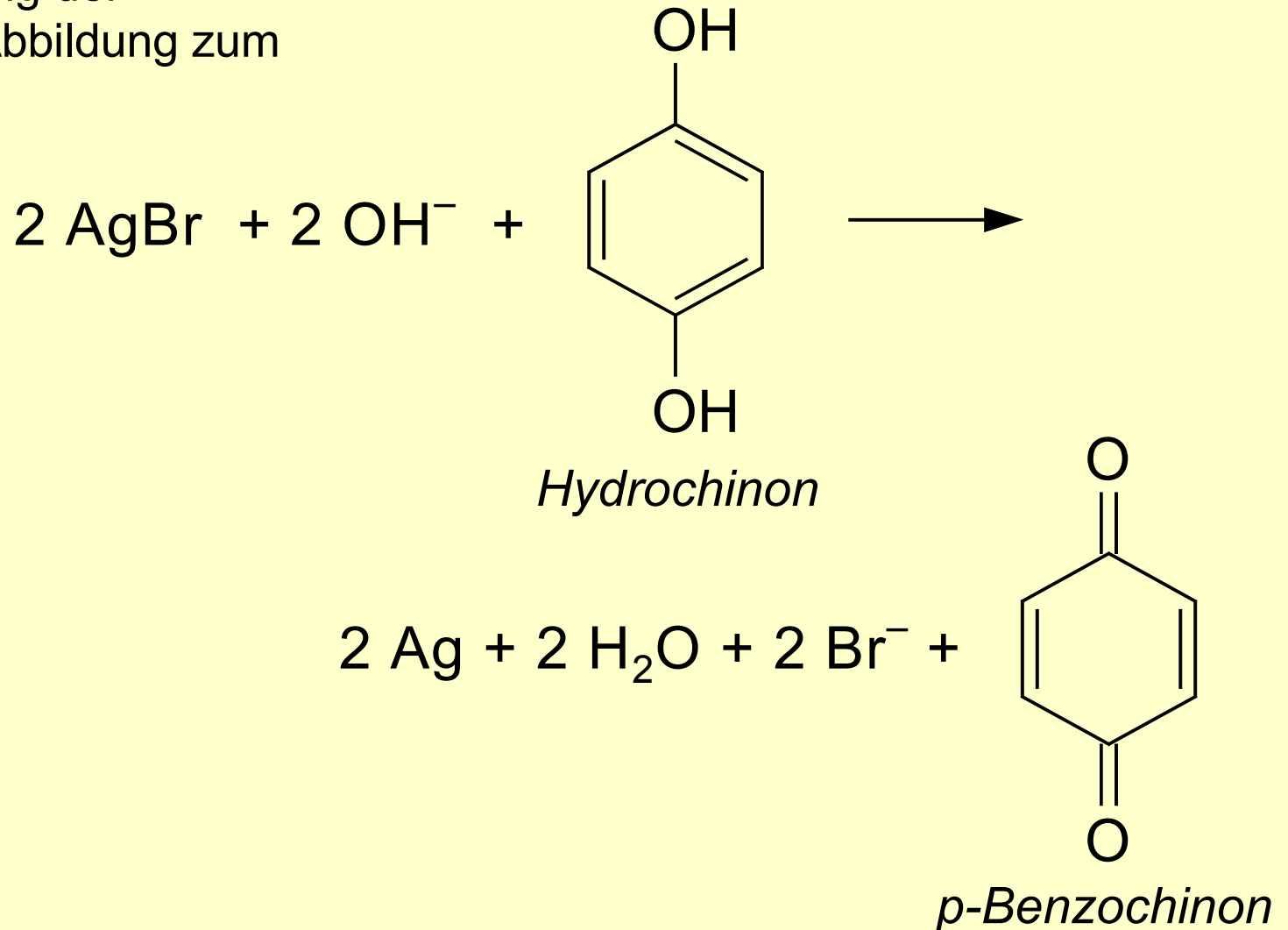
# Der fotografische Prozess

Belichtung der lichtempfindlichen Schicht zum Erhalten einer latenten Abbildung



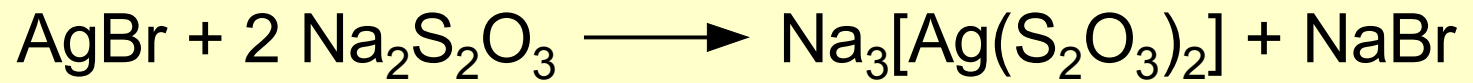
# Der fotografische Prozess

Entwicklung der  
latenten Abbildung zum  
Negativ

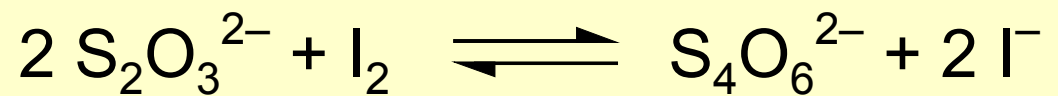
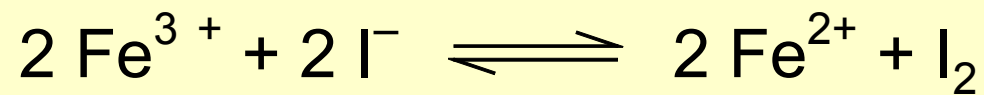
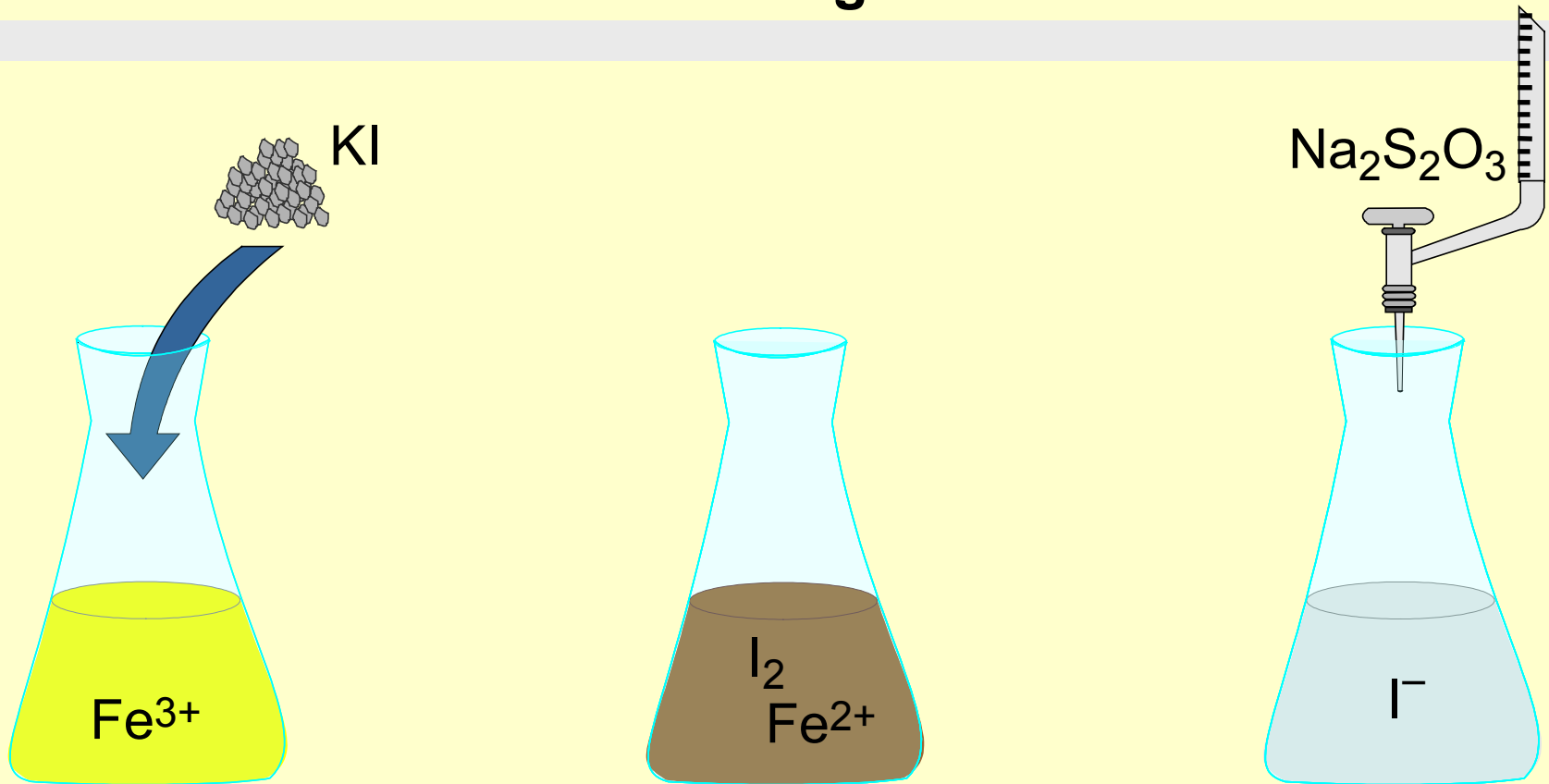


# Der fotografische Prozess

Fixierung



# Iodometrische Bestimmung von Oxidationsmitteln



# Iodometrische Bestimmung von Reduktionsmitteln

