

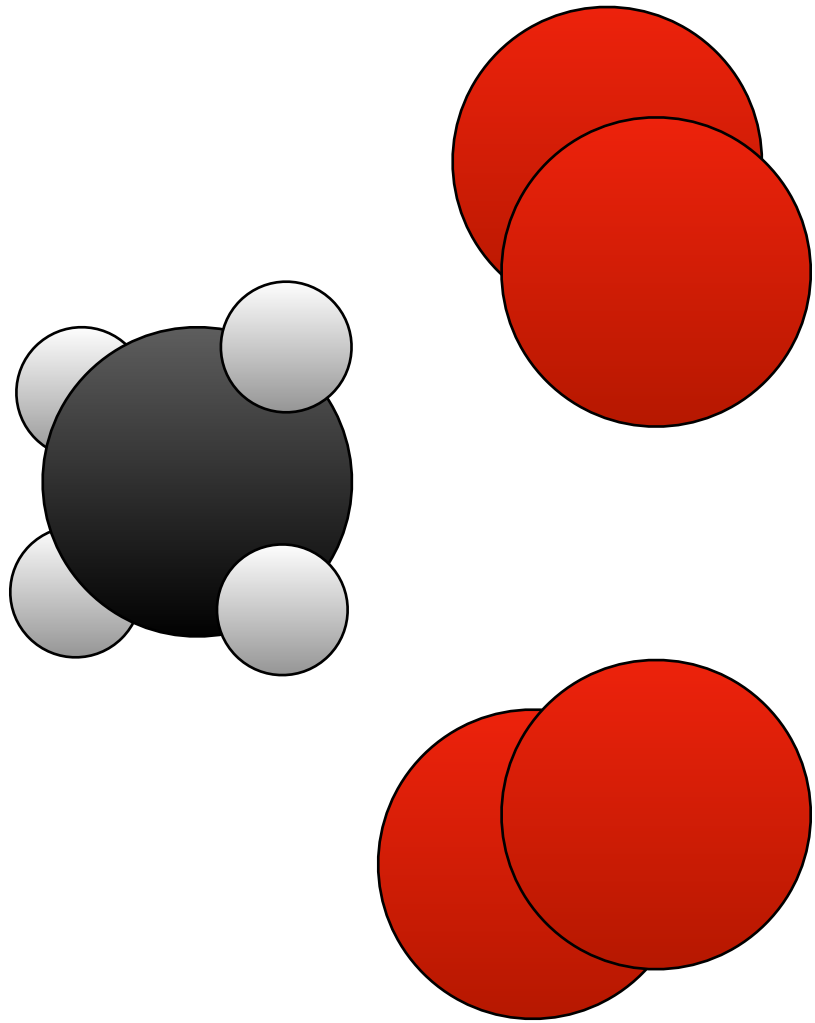
⁴²**Mo** dèles de
²⁰**Ca** lcul
¹¹**Na** turel

Anto**Nio** E. Por**Reca**
aeporreca.org/mocana

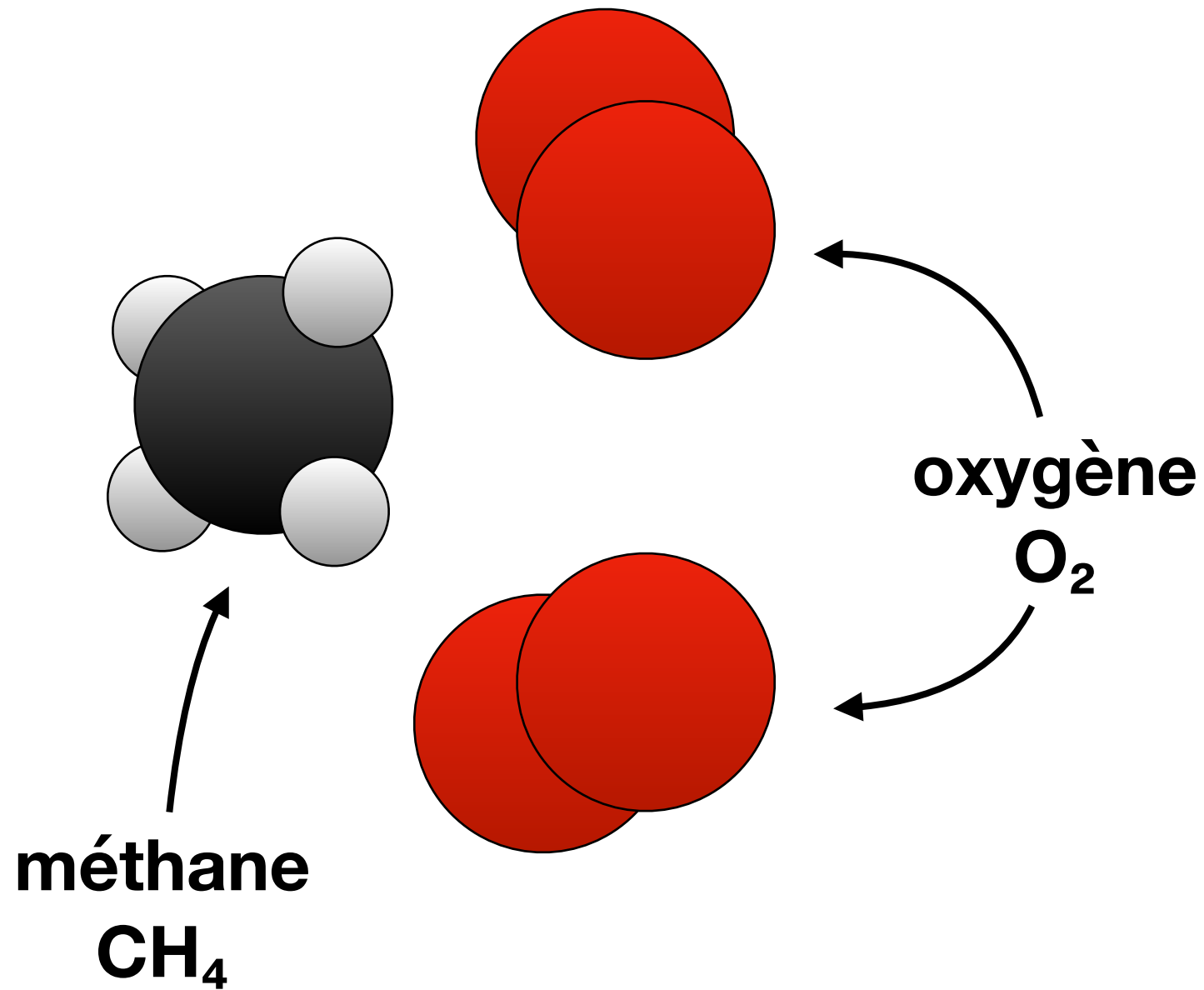
**Calculer avec des
réactions chimiques**



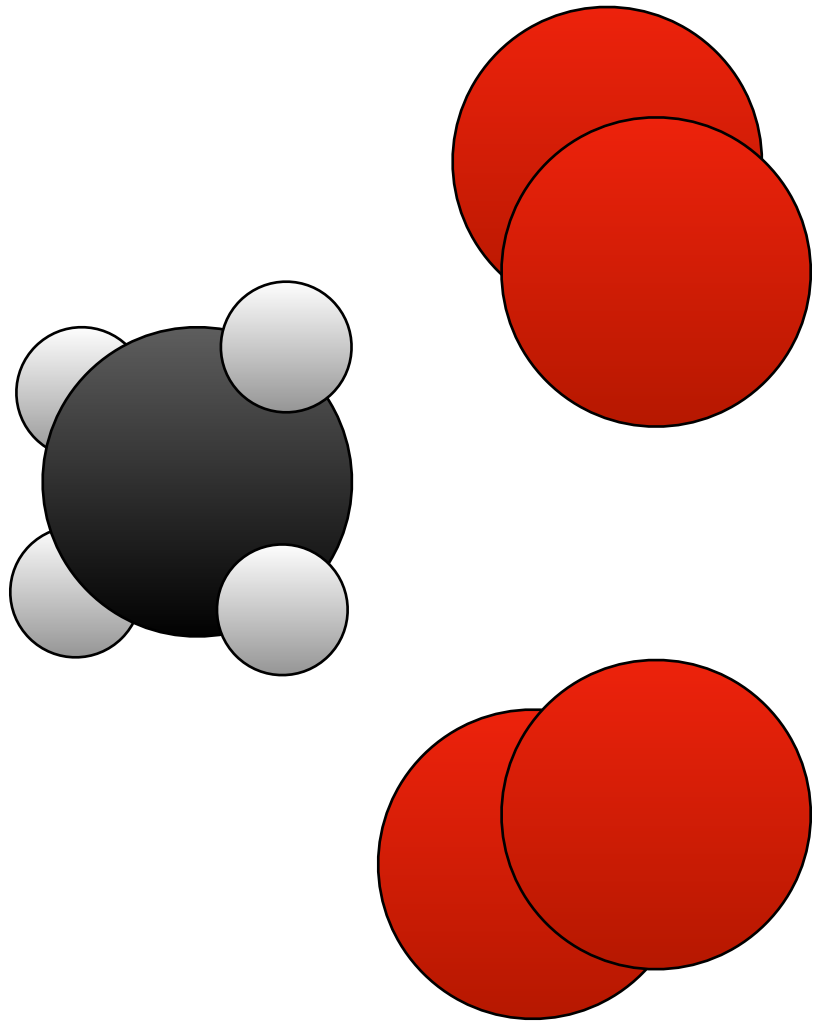
Combustion du méthane



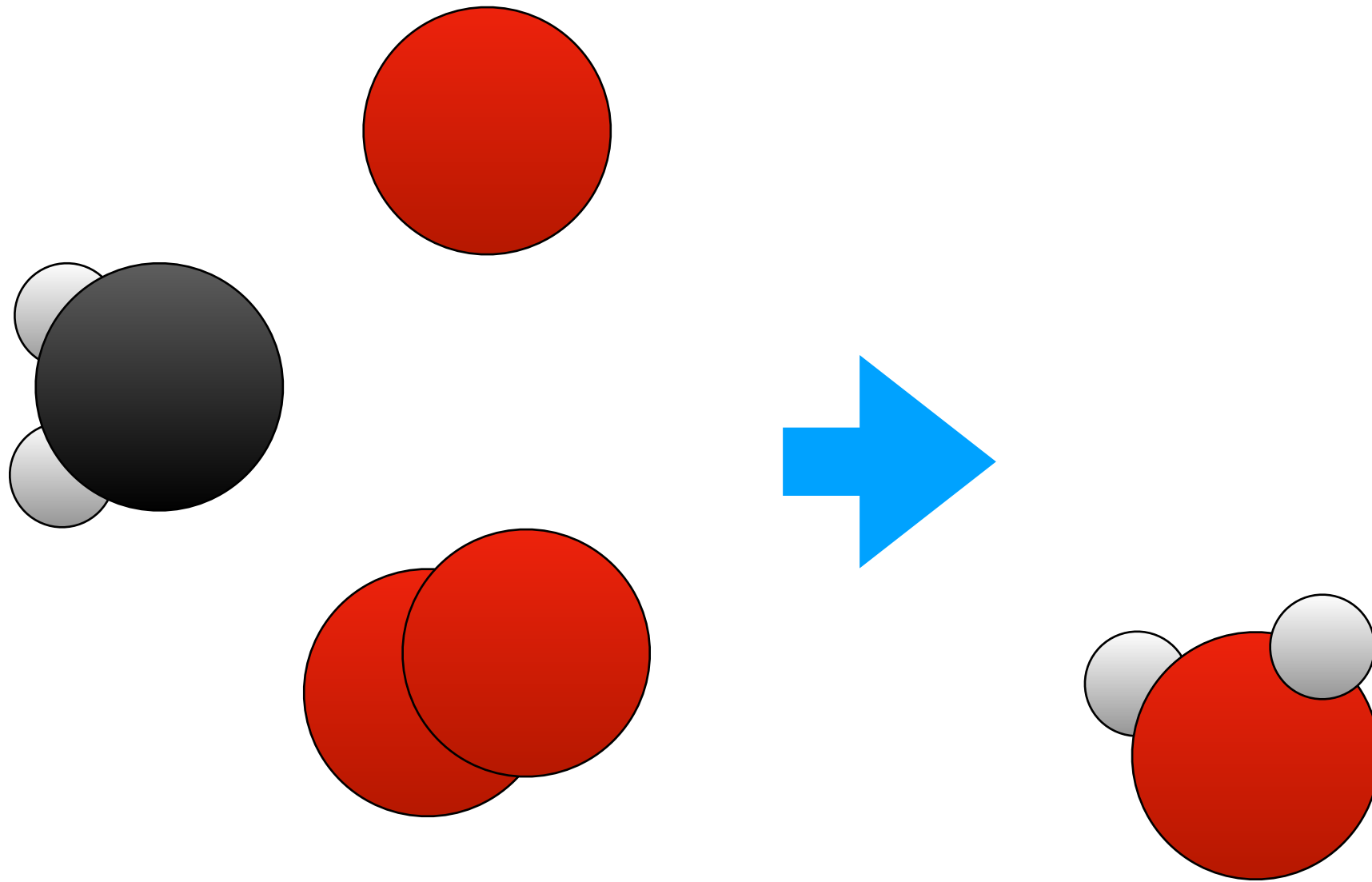
Combustion du méthane



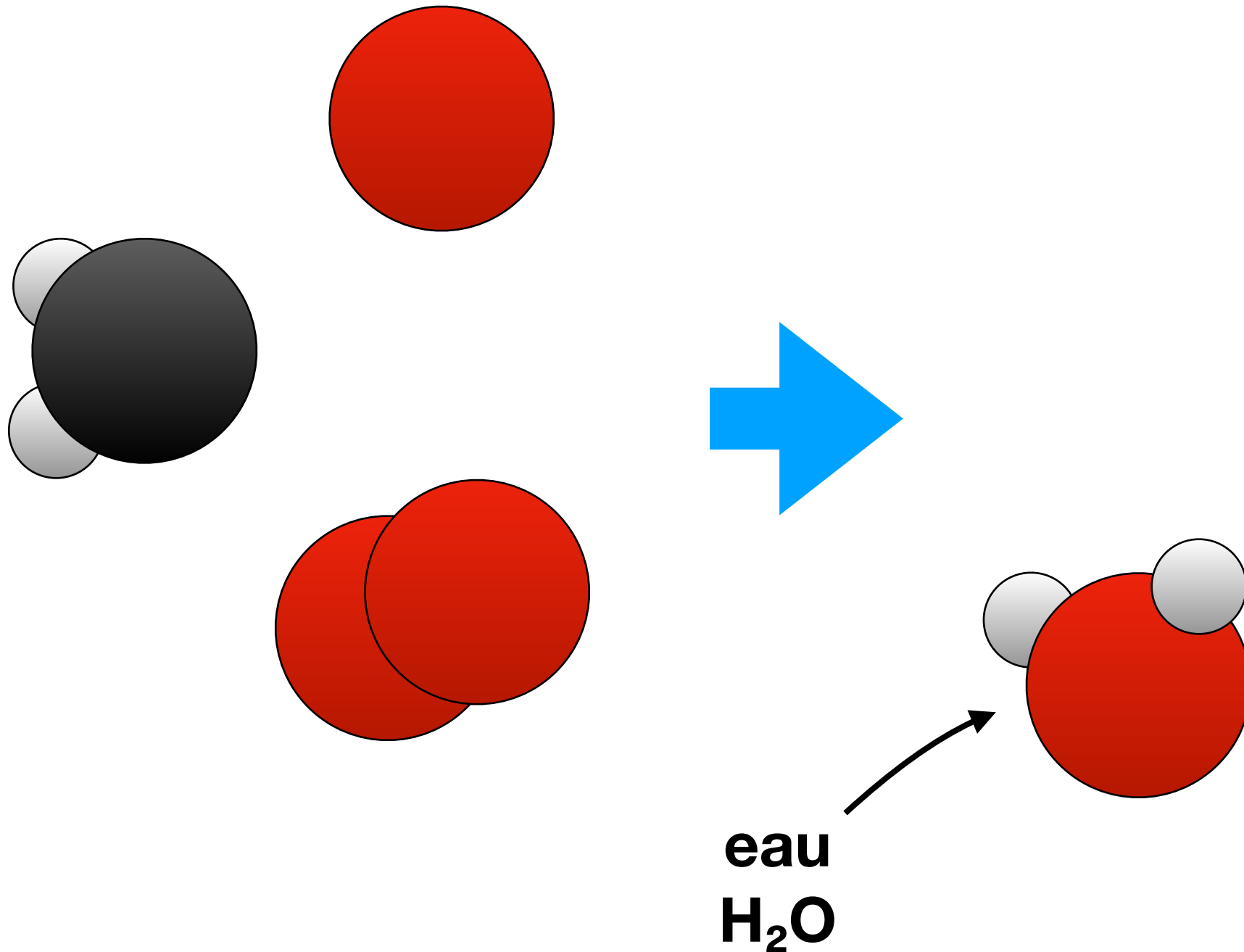
Combustion du méthane



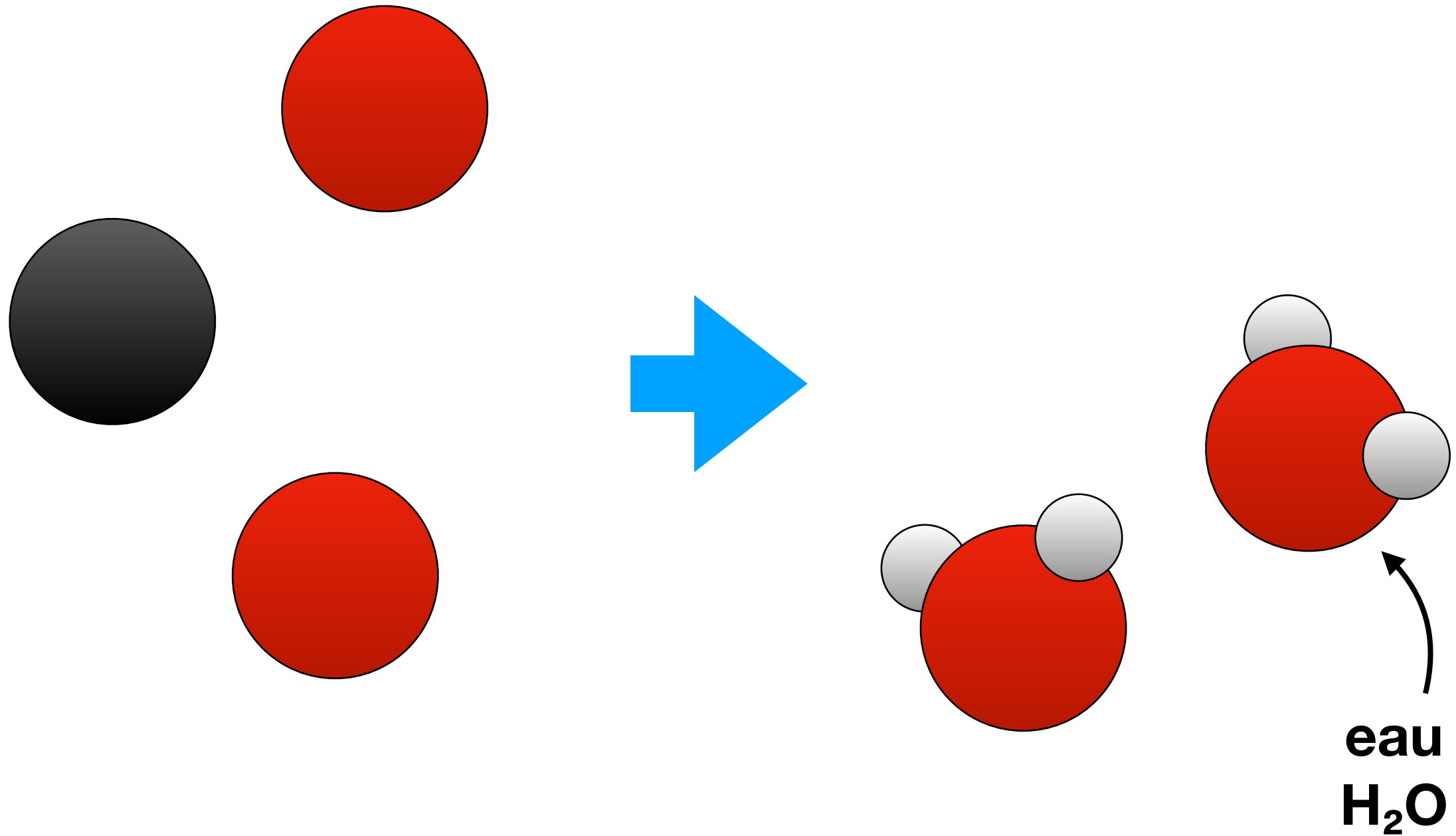
Combustion du méthane



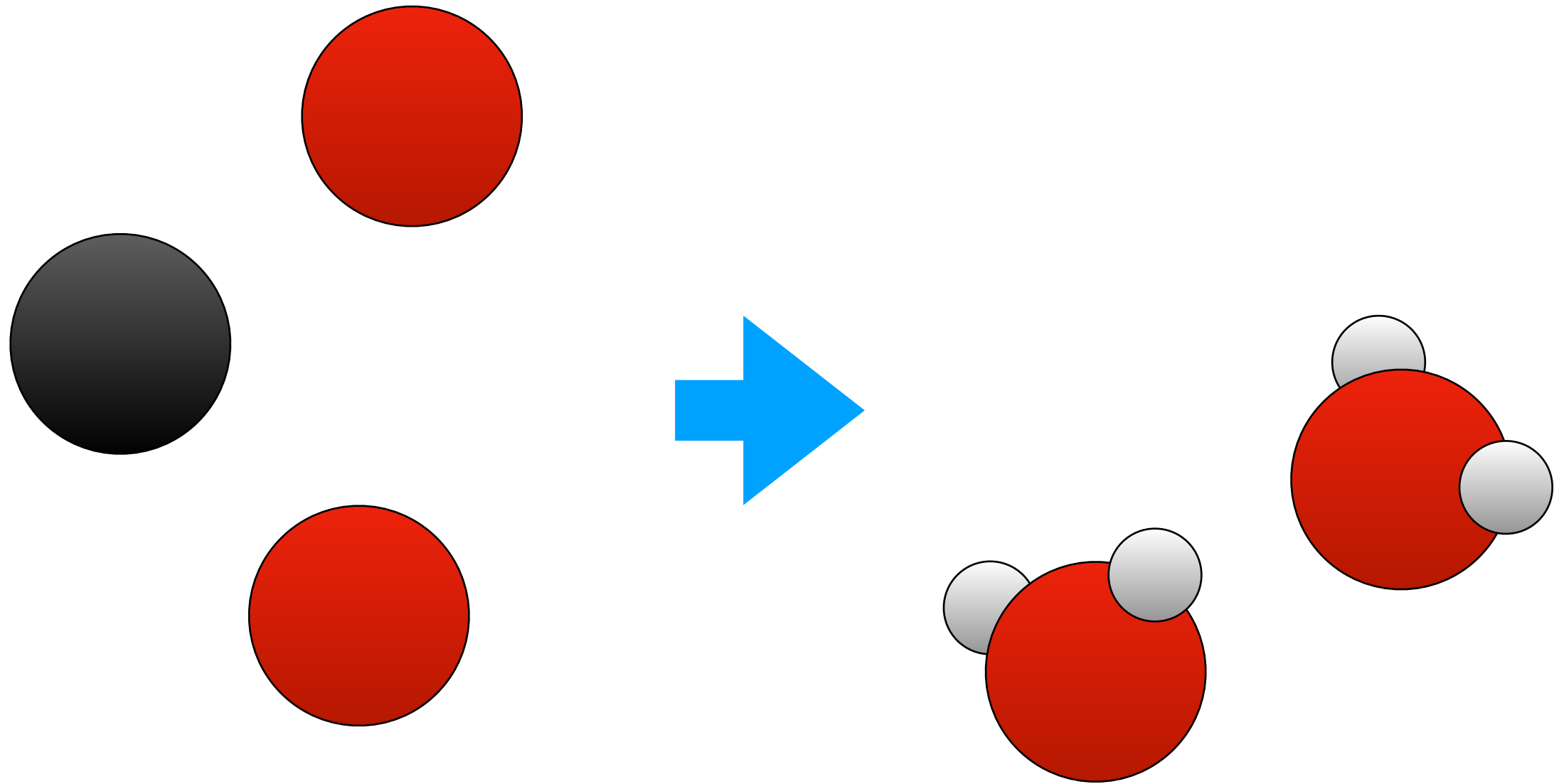
Combustion du méthane



Combustion du méthane

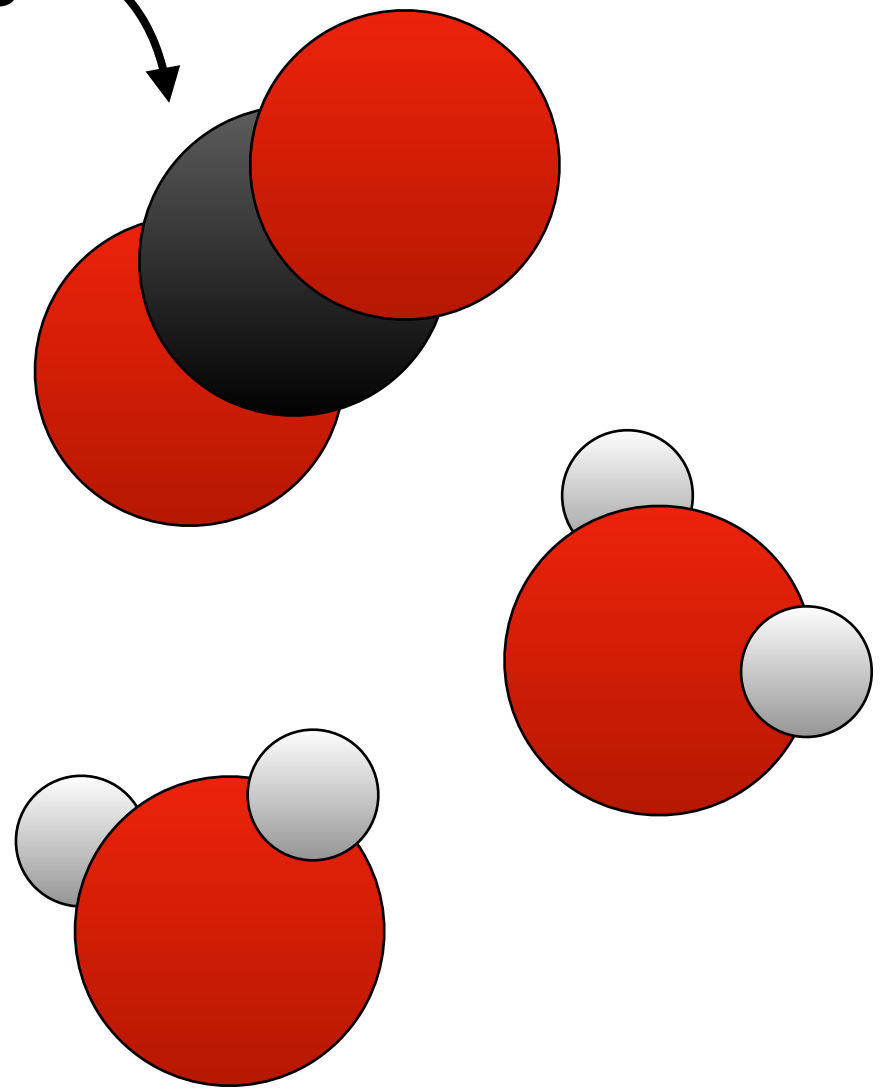
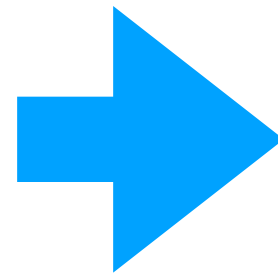


Combustion du méthane

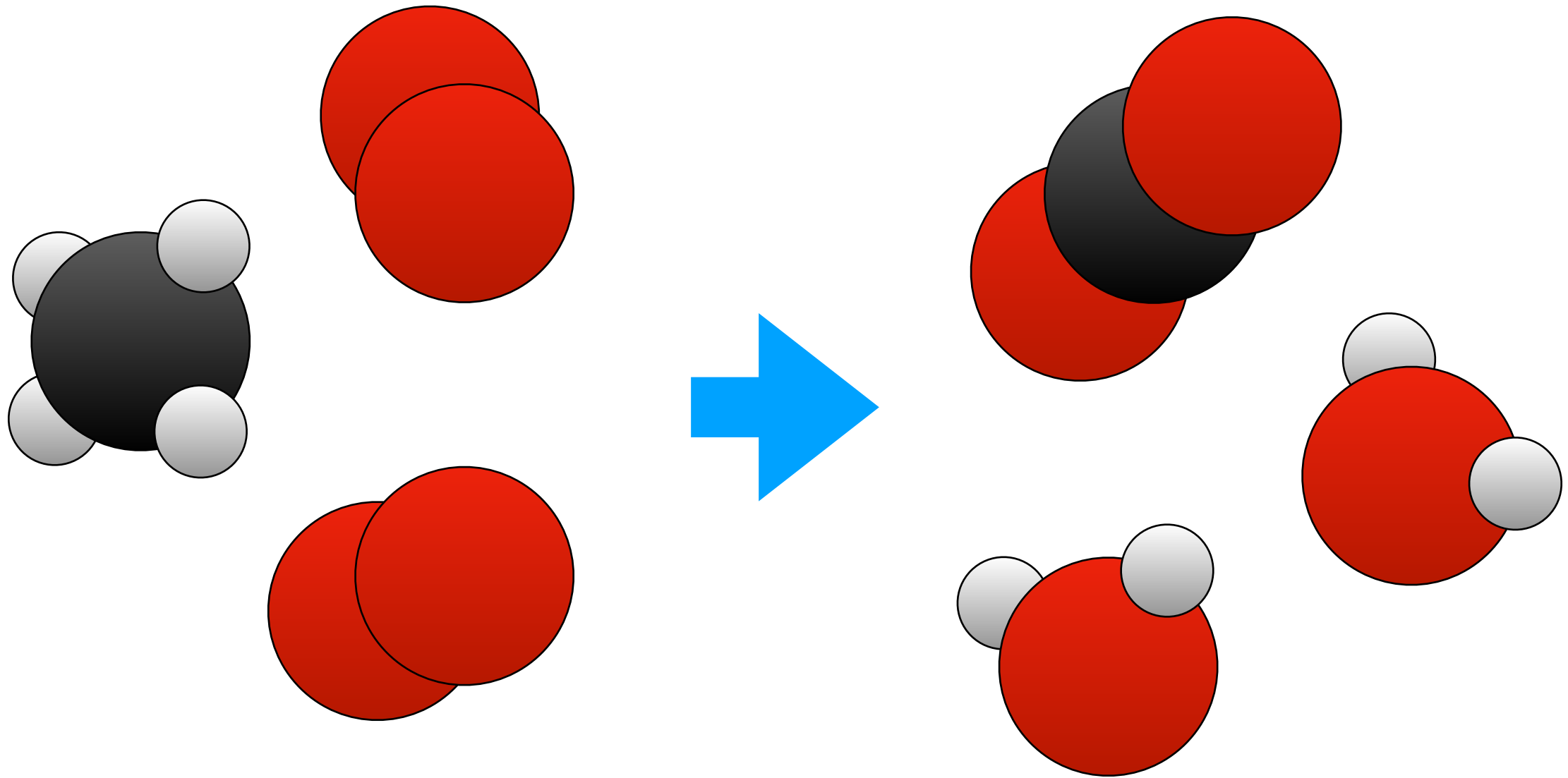


Combustion du méthane

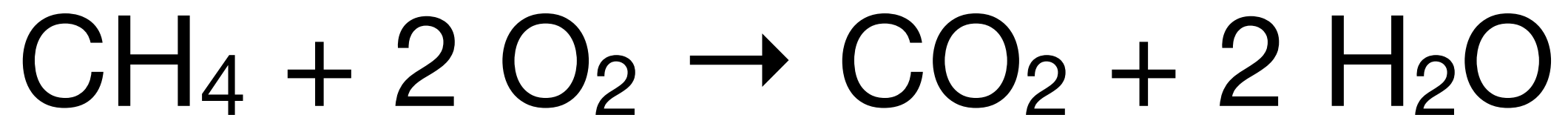
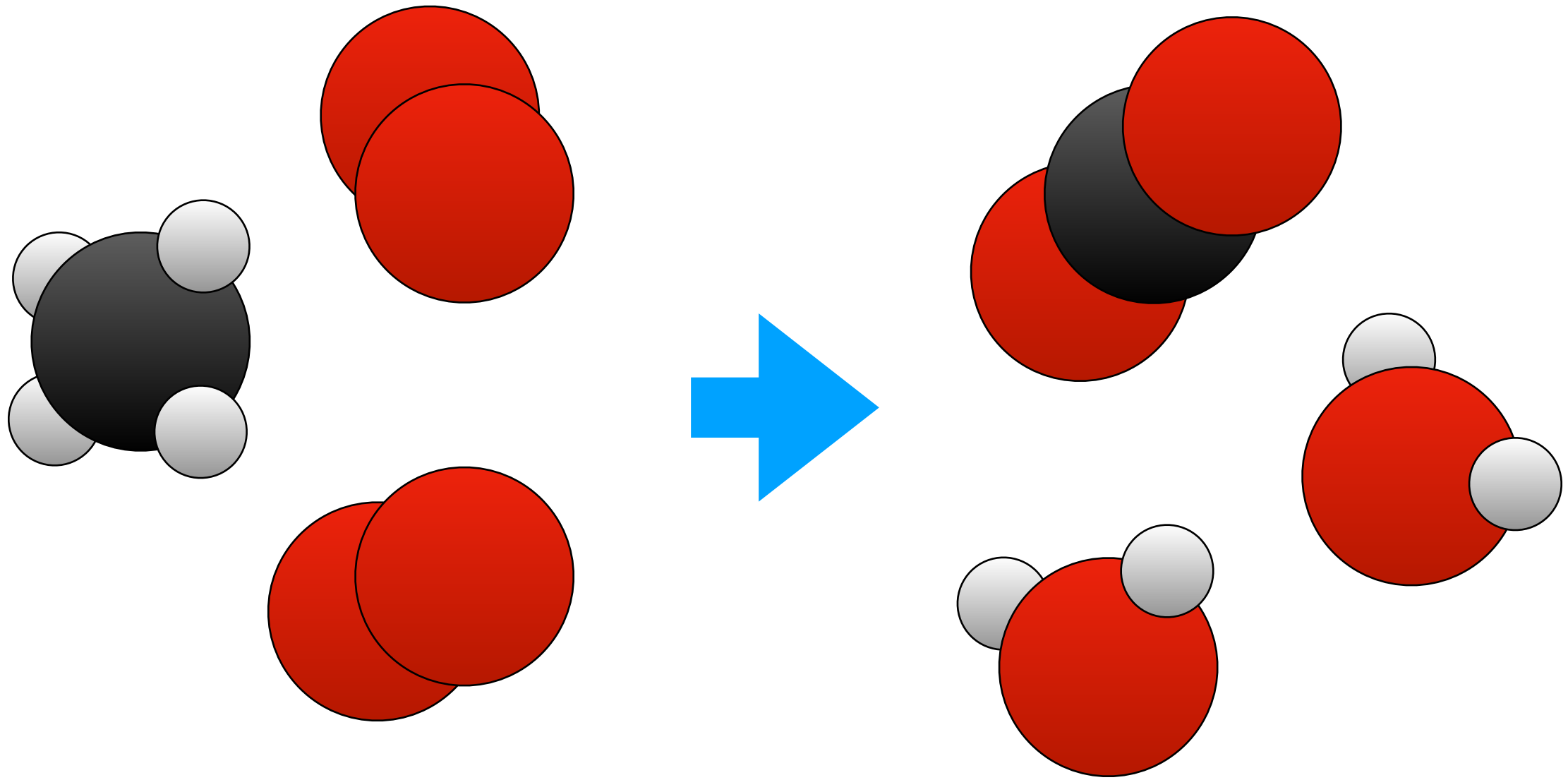
dioxyde
de carbone
 CO_2



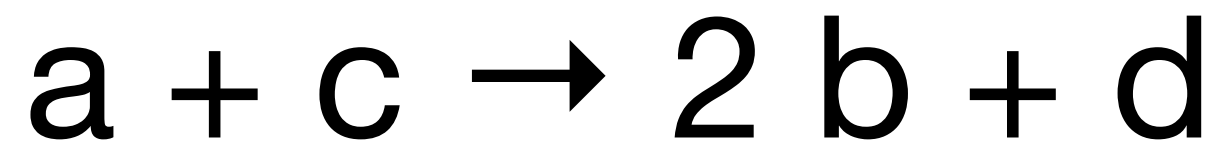
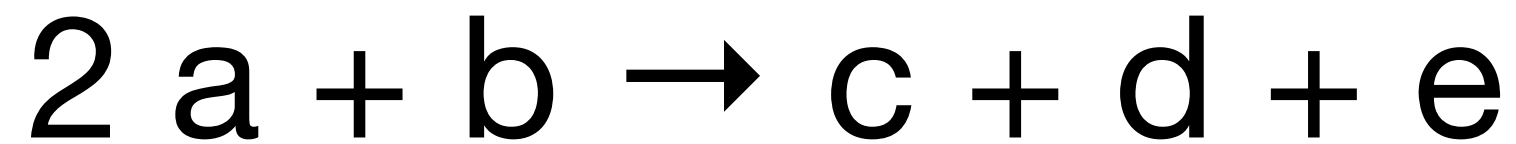
Combustion du méthane



Combustion du méthane



Réactions chimiques abstraites

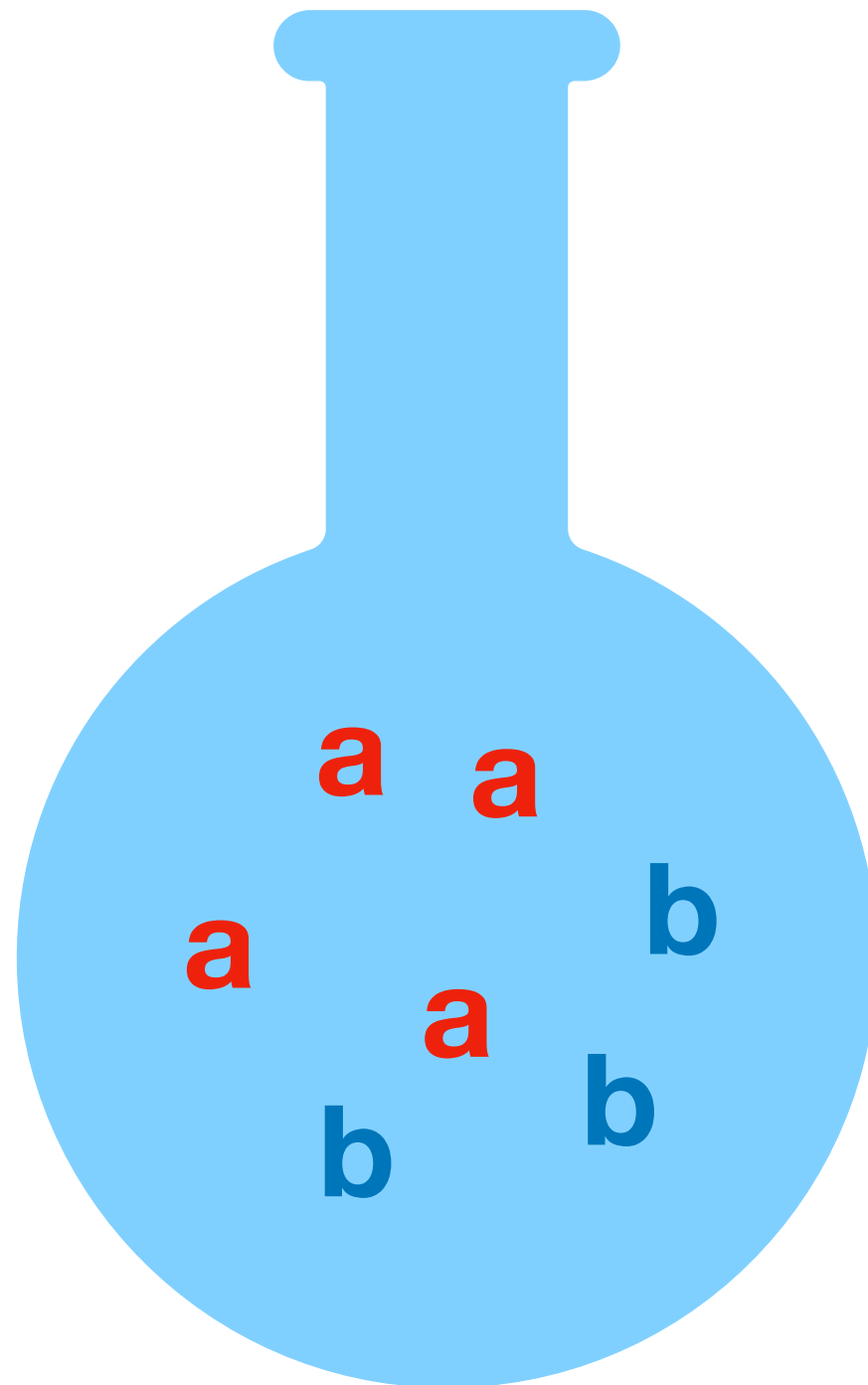


Calcul avec les réactions chimiques

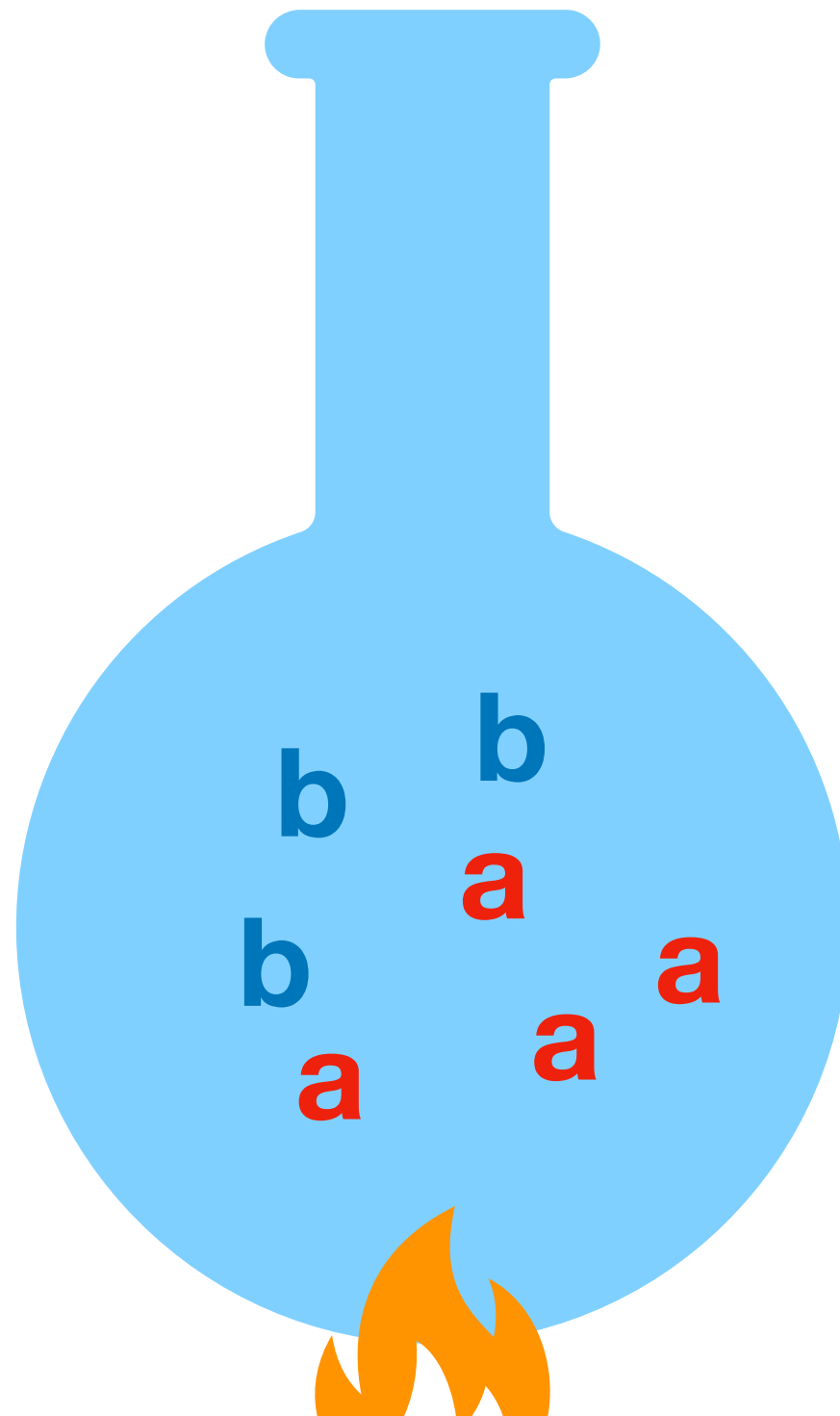
On prend un ballon



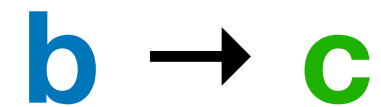
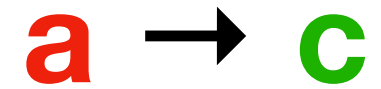
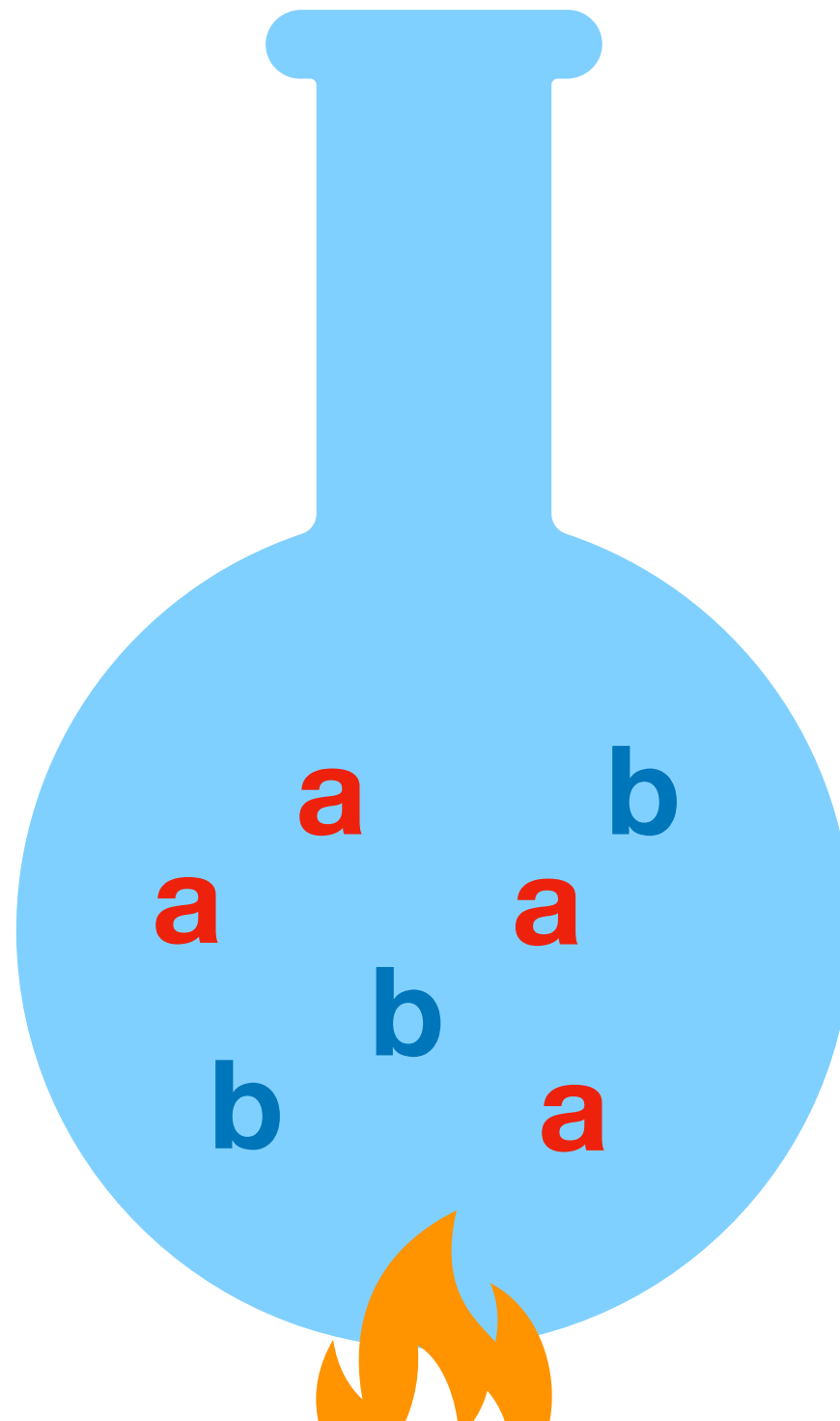
On y verse des molécules



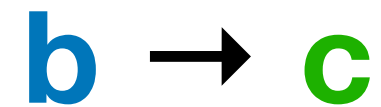
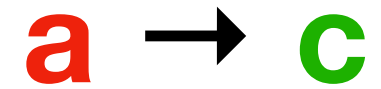
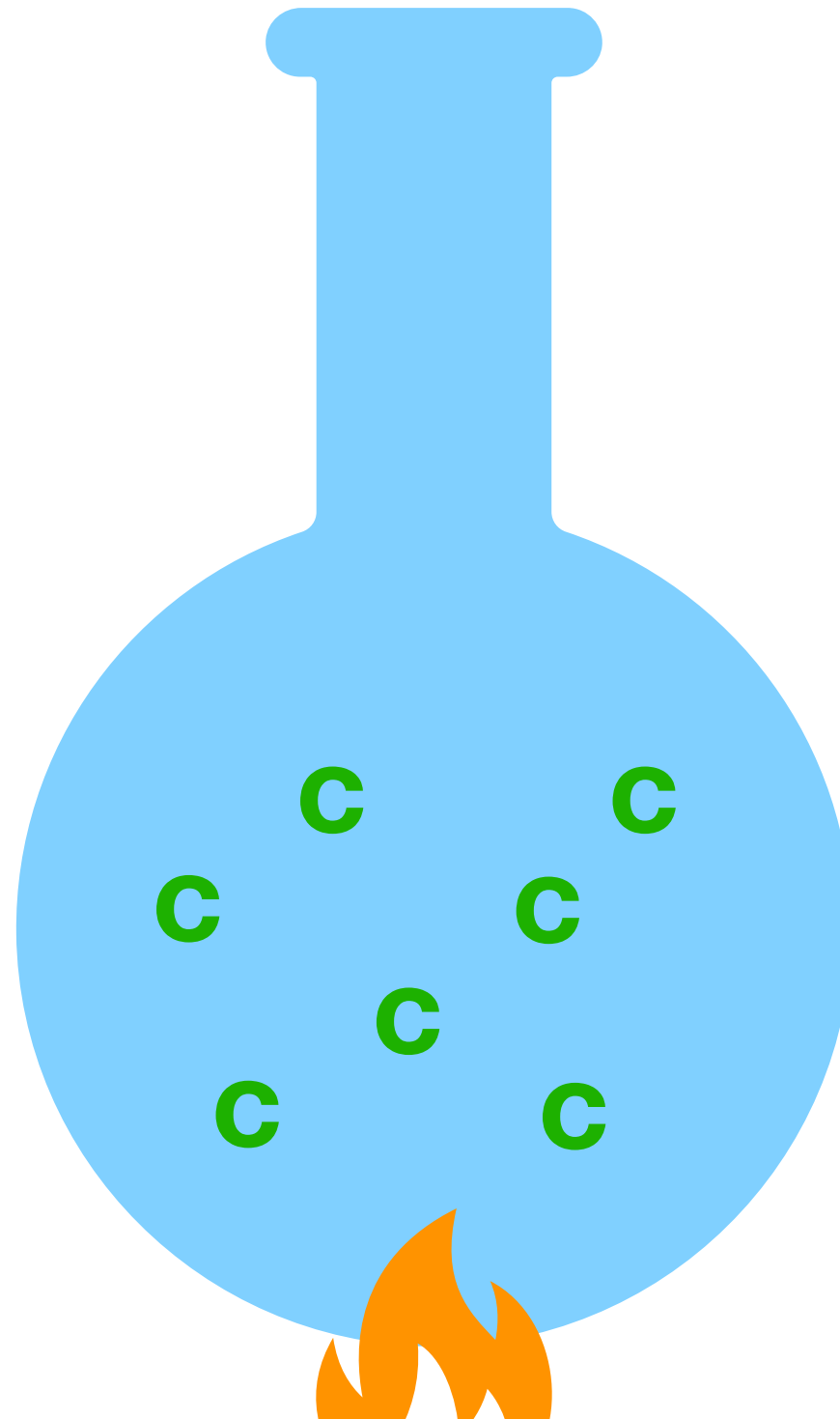
On chauffe



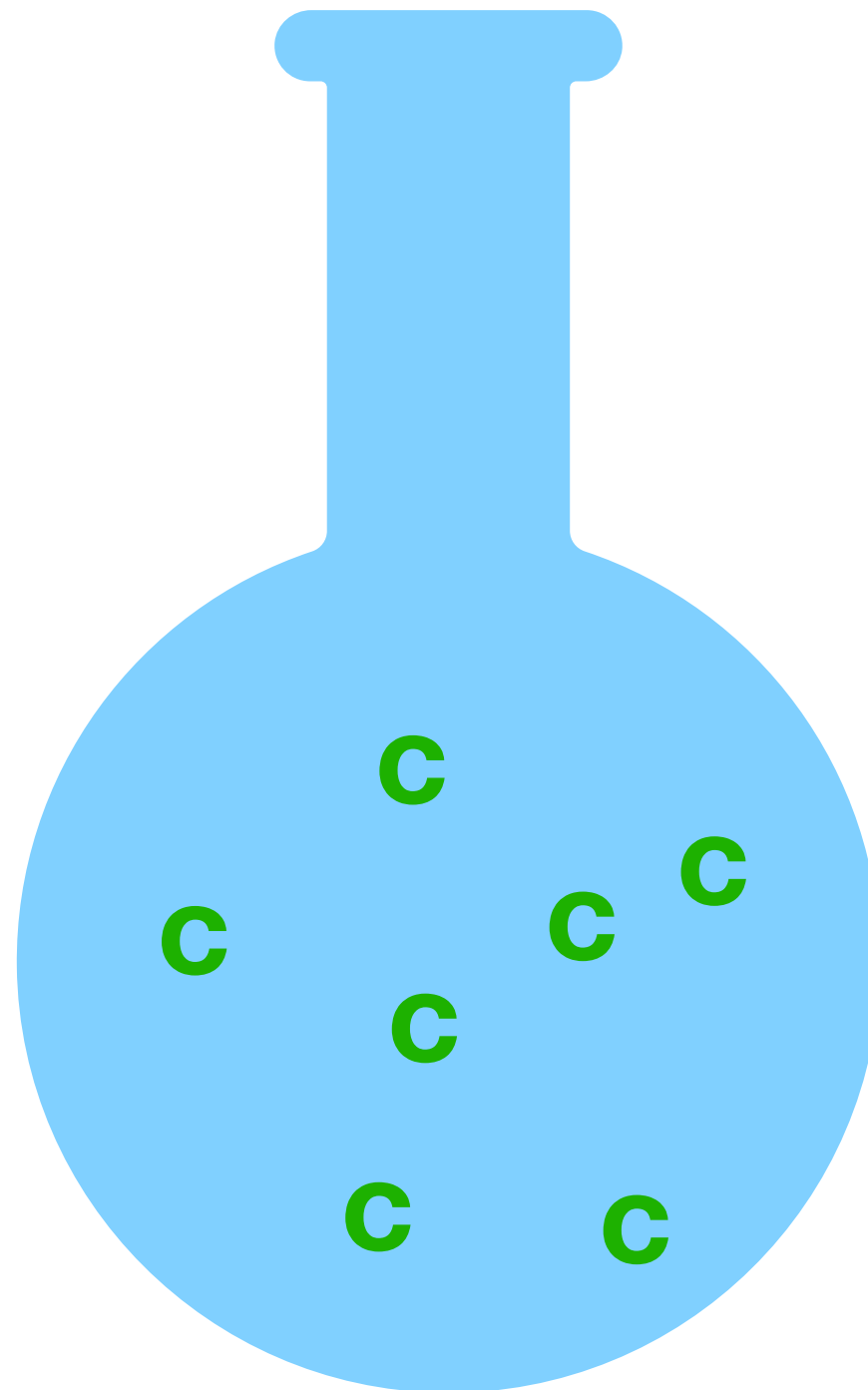
Les réactions on lieu simultanément



Les réactions on lieu simultanément



On laisse refroidir
et on interprète le résultat



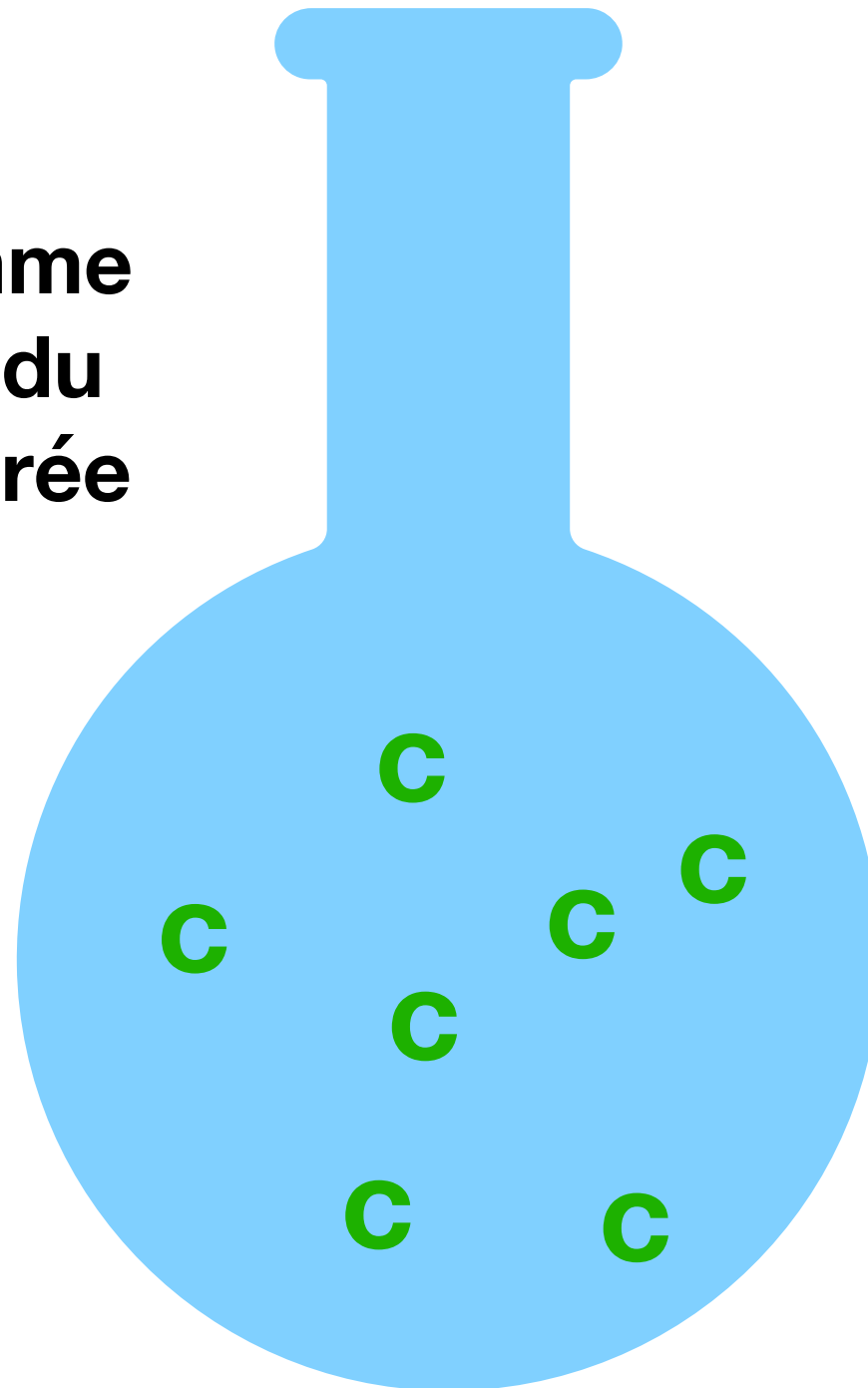
a → **c**

b → **c**

On laisse refroidir et on interprète le résultat

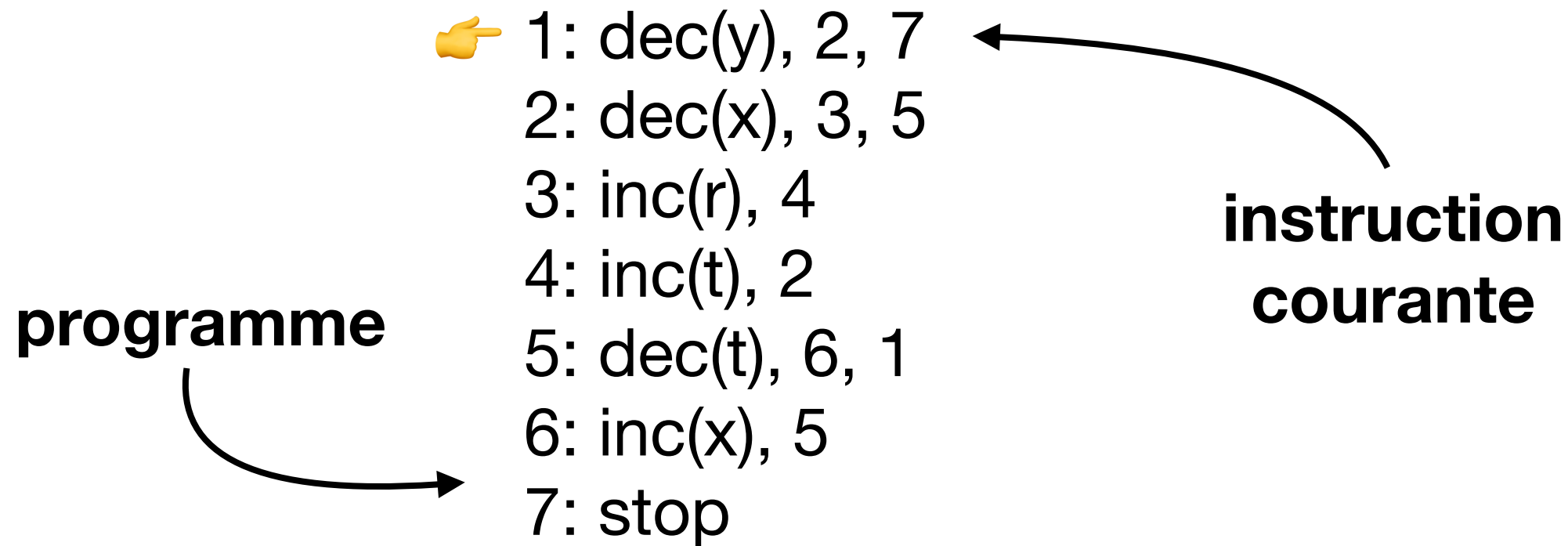
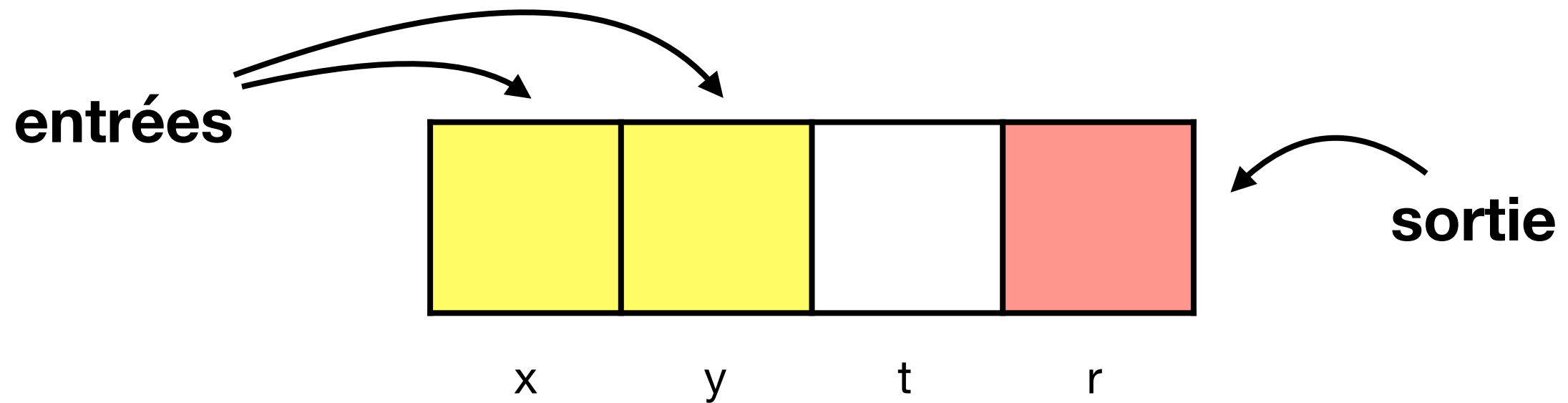
le nombre de **c**
en sortie est la somme
du nombre de **a** et du
nombre de **b** en entrée

a → **c**
b → **c**



Interlude : les machines à registres, un modèle universel

Machines à registres



Trois types d'instructions

3: `inc(r)`, 4

instruction 3 :
incrémente le registre `r`
et passe à l'instruction 4

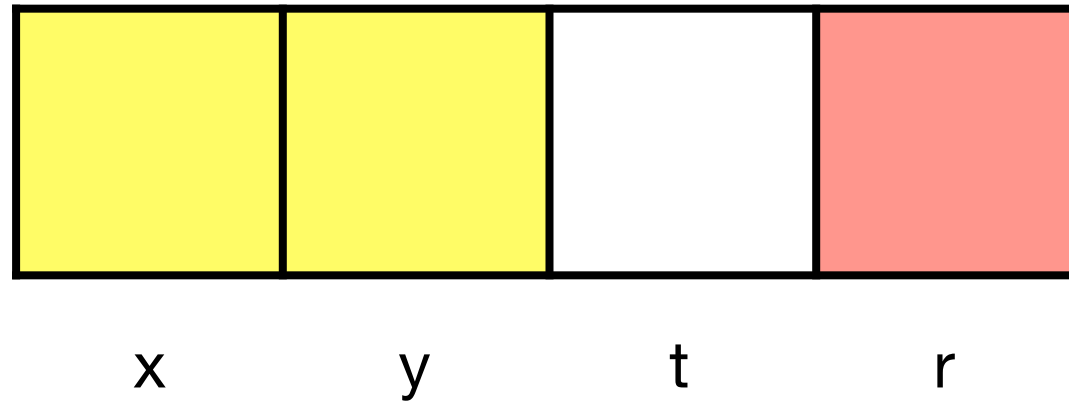
5: `dec(t)`, 6, 1

instruction 5 : si le registre `t`
est supérieur à 0, alors
décrémente-le et passe
à l'instruction 6, sinon laisse-le
à 0 et passe à l'instruction 1

7: `stop`

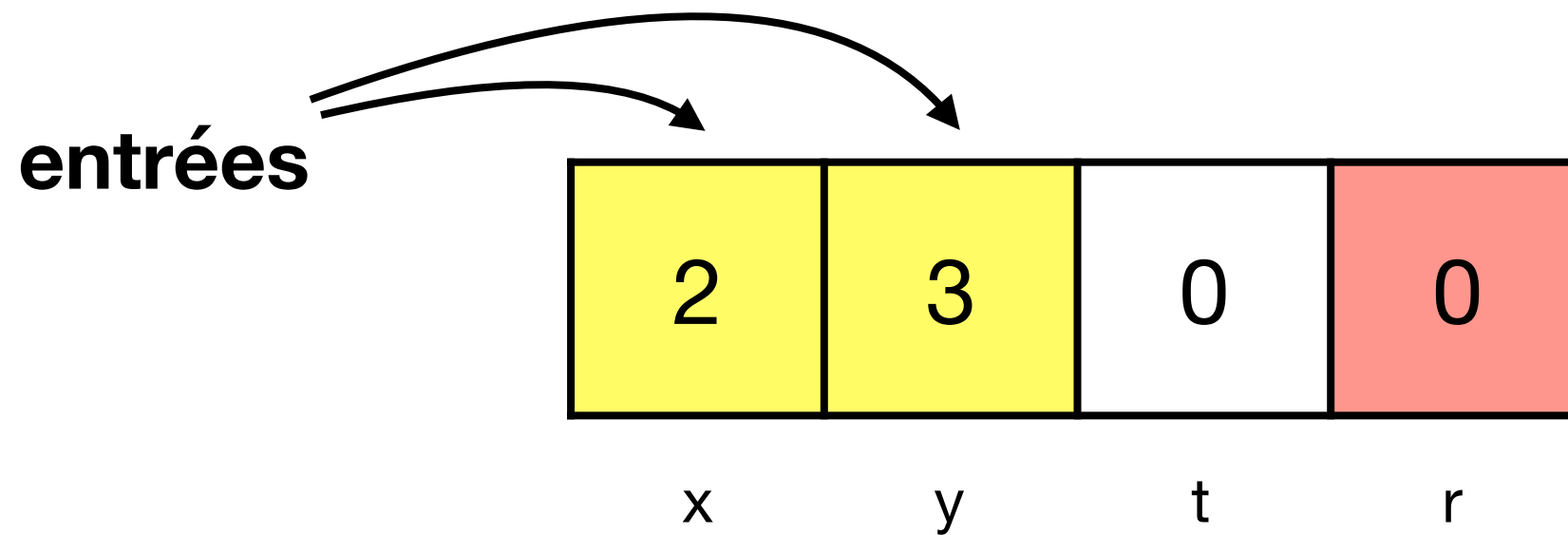
instruction 7 : on s'arrête

Machines à registres



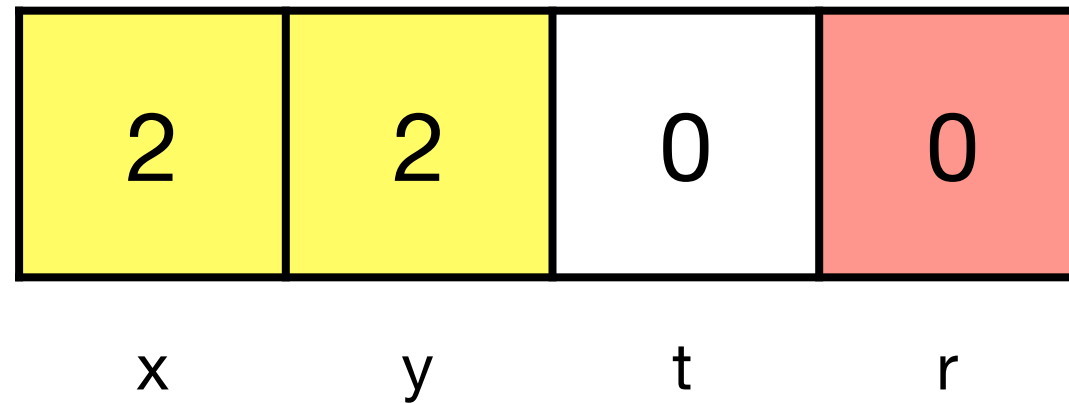
- 👉 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



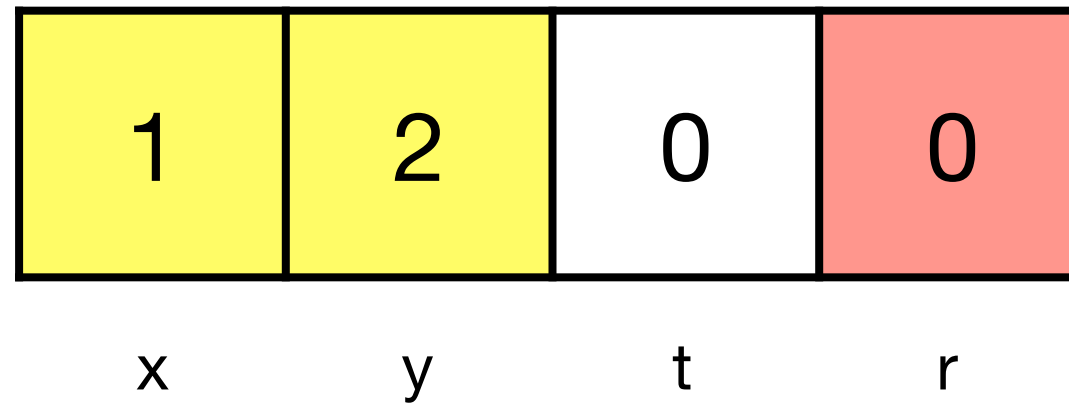
- 👉 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



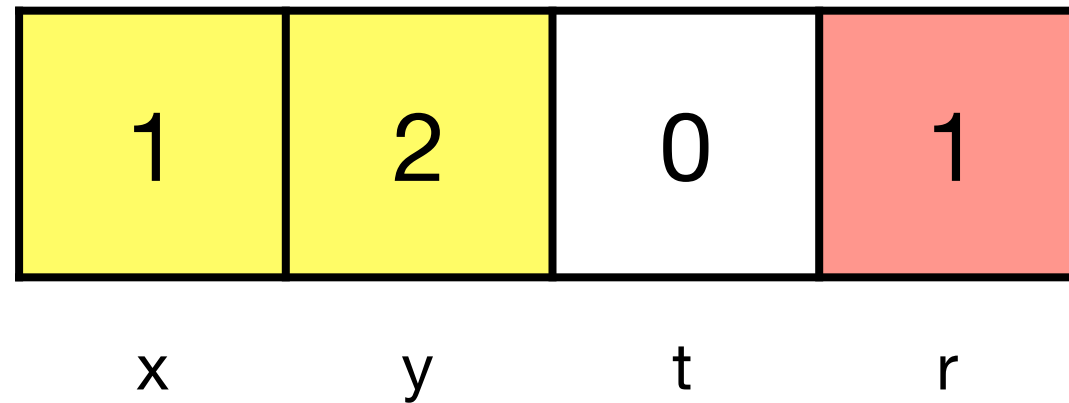
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



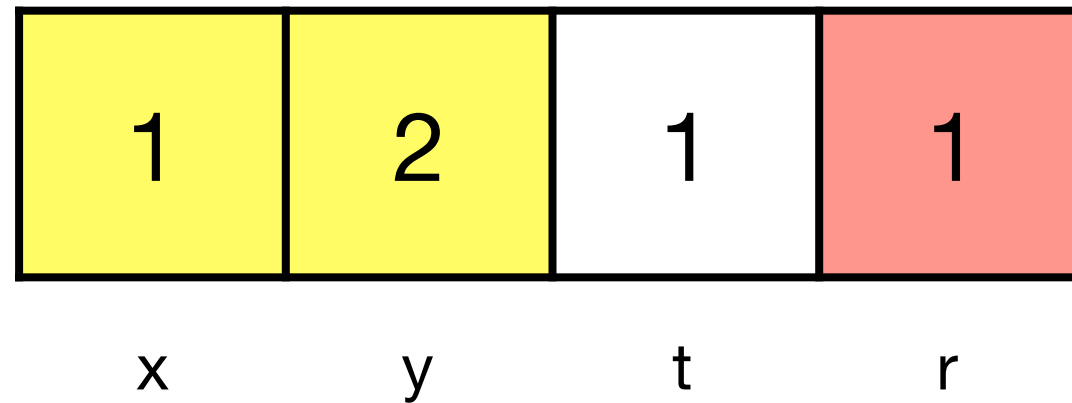
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



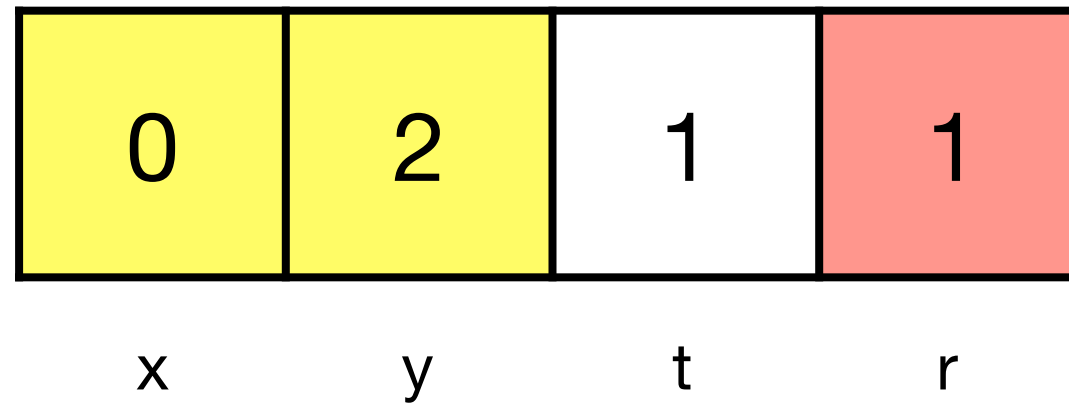
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



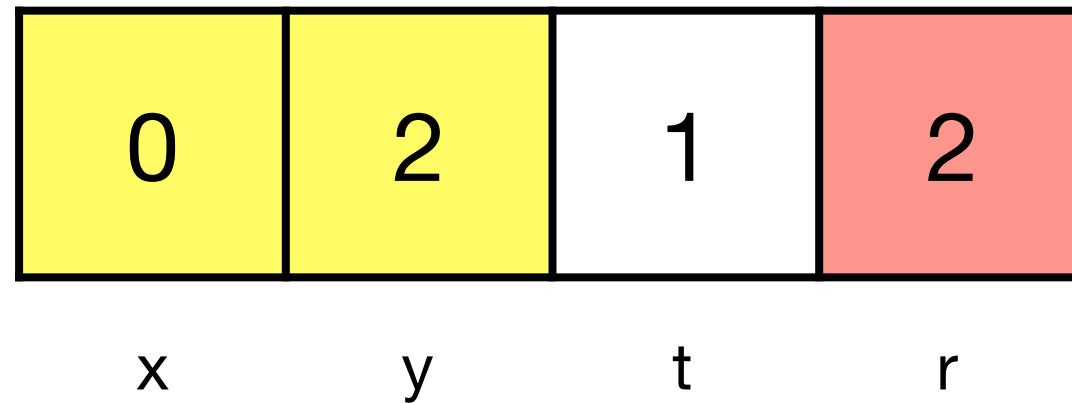
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



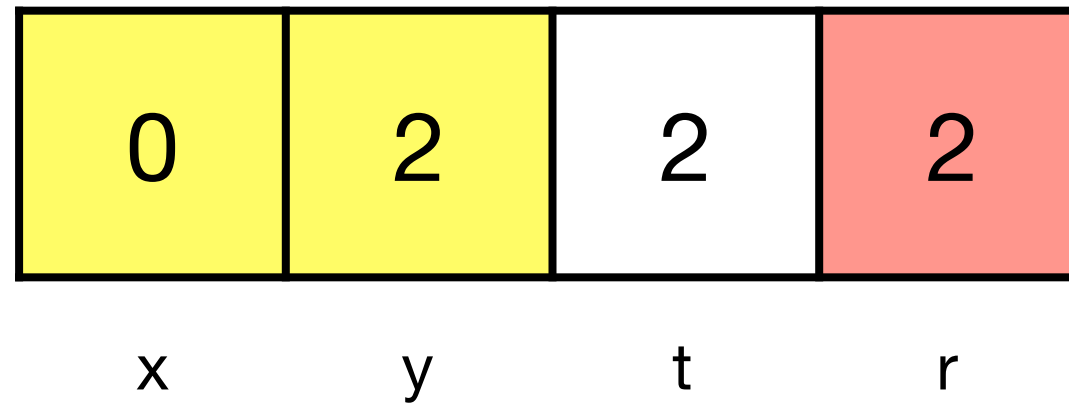
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



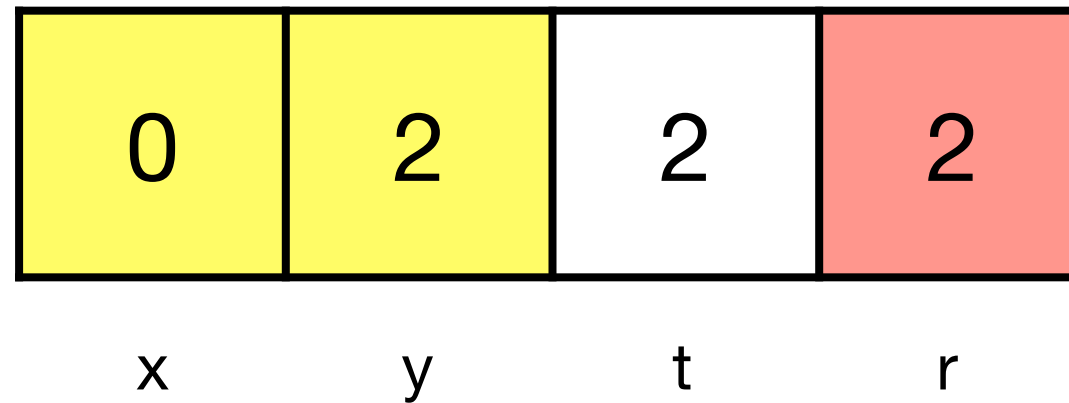
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



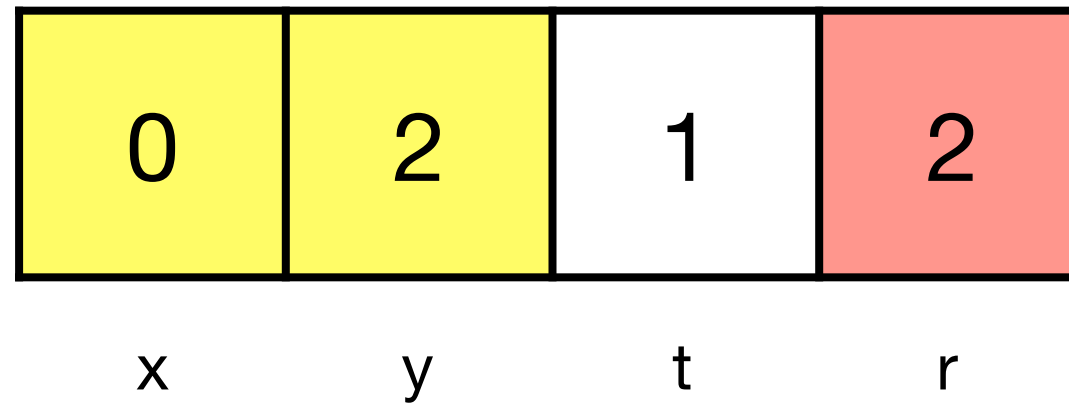
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



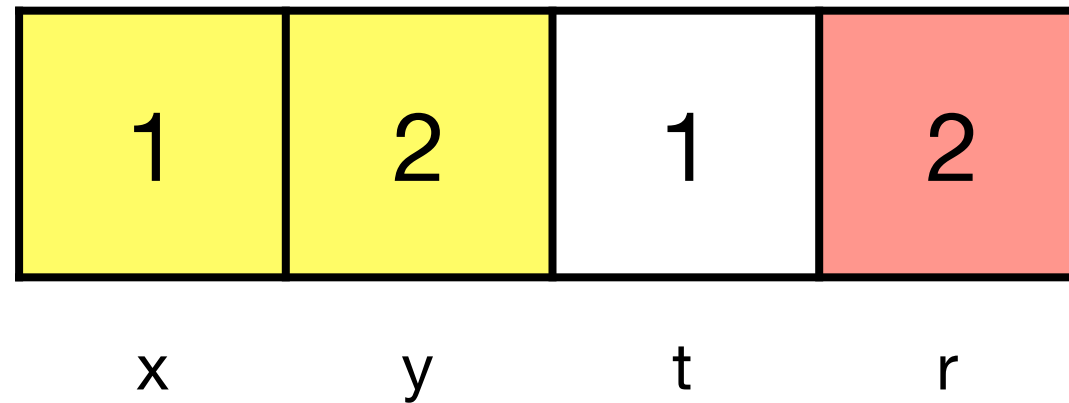
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



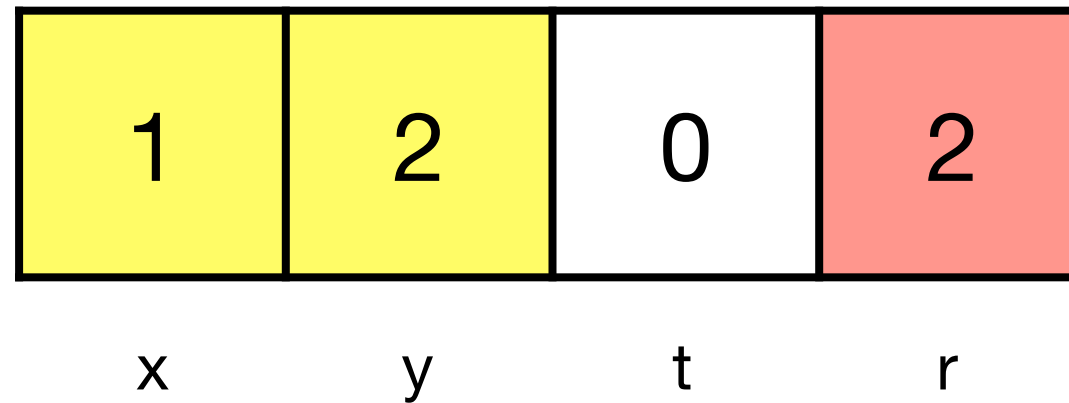
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



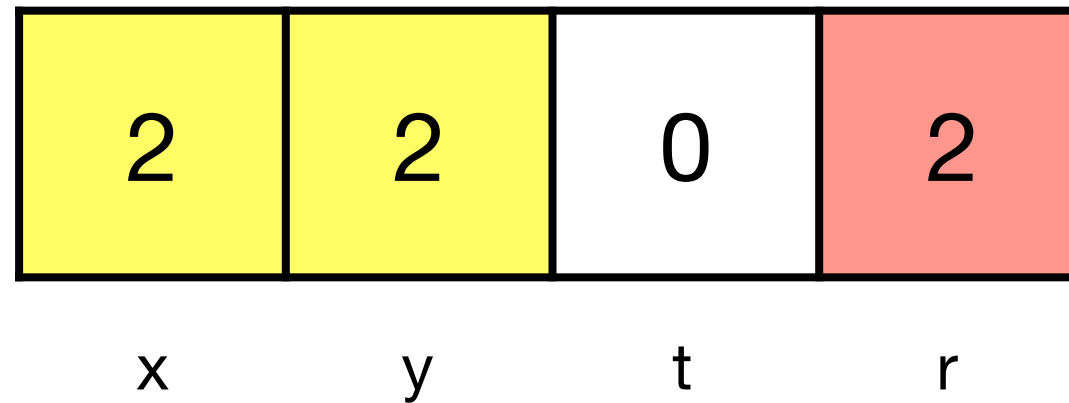
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



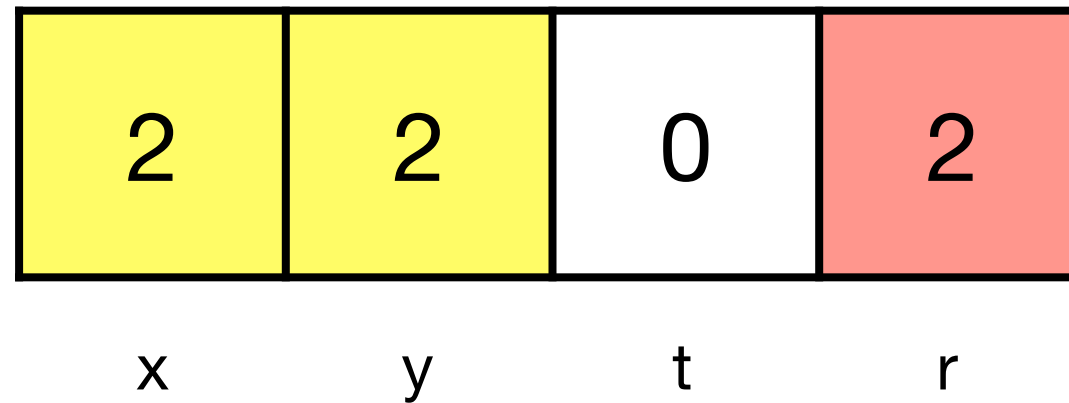
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



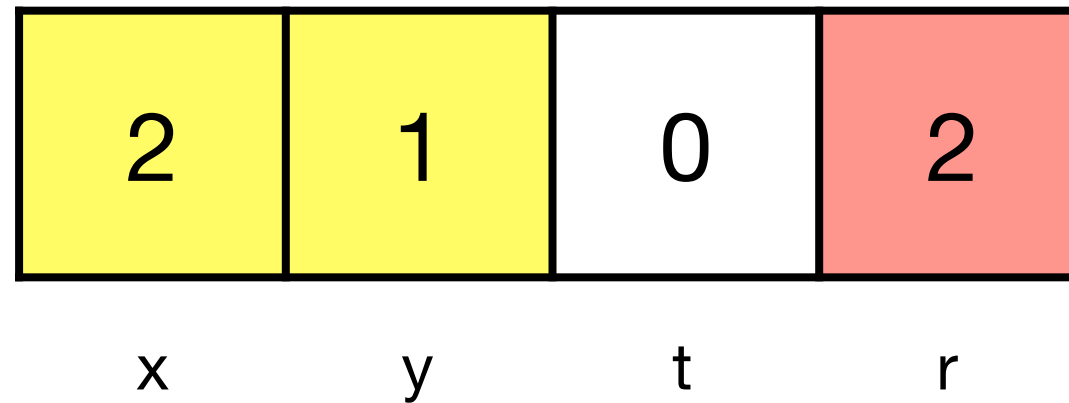
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



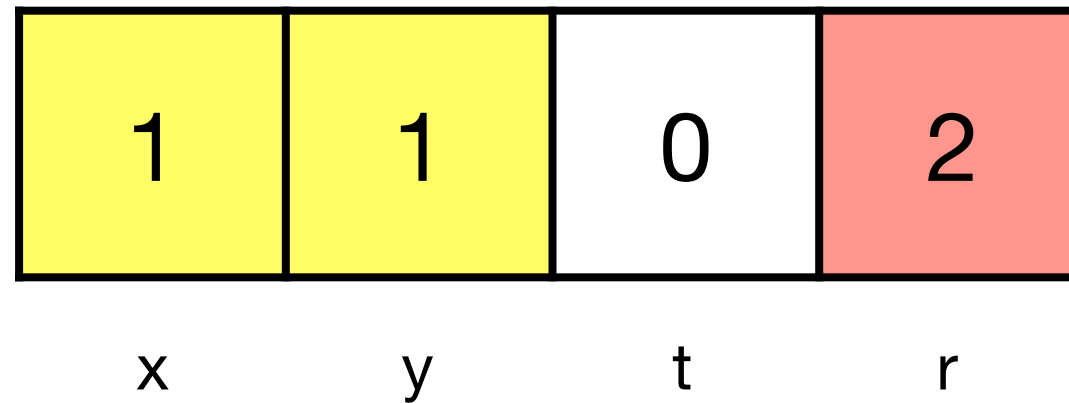
- 👉 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



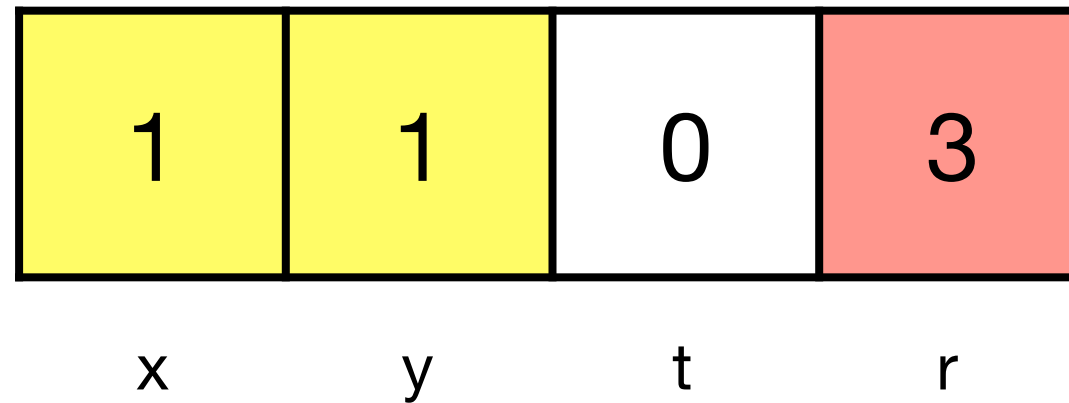
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



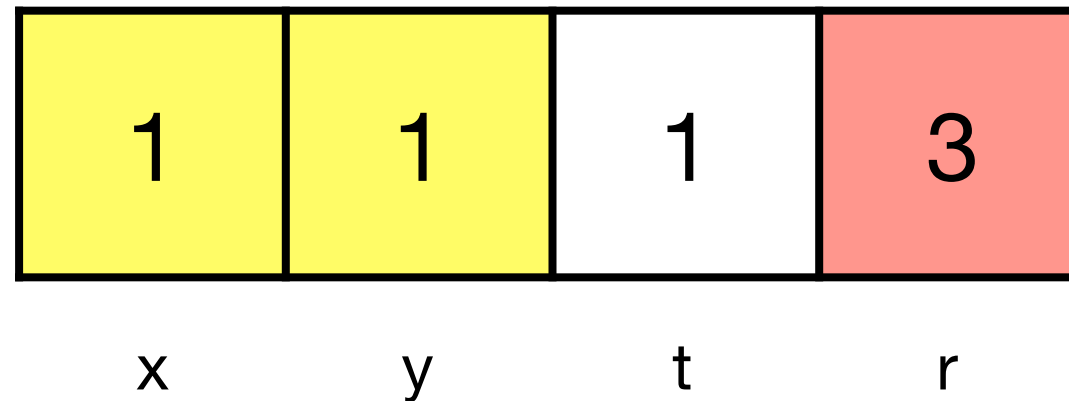
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



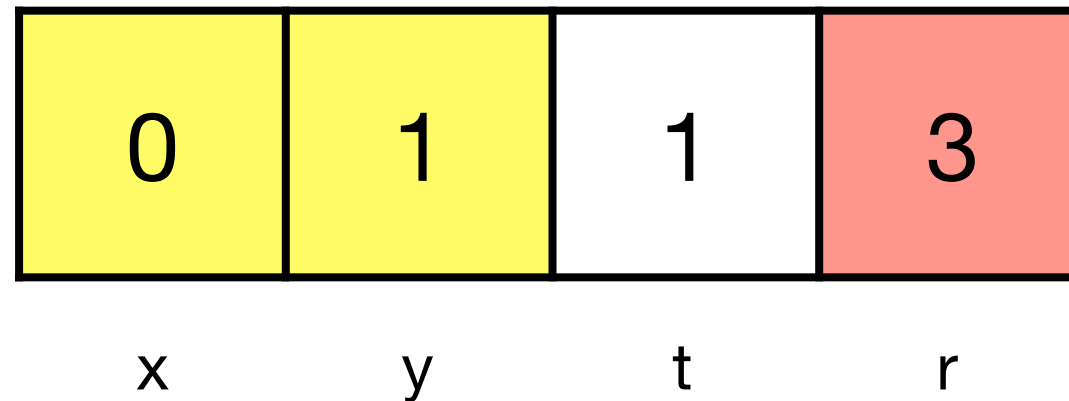
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



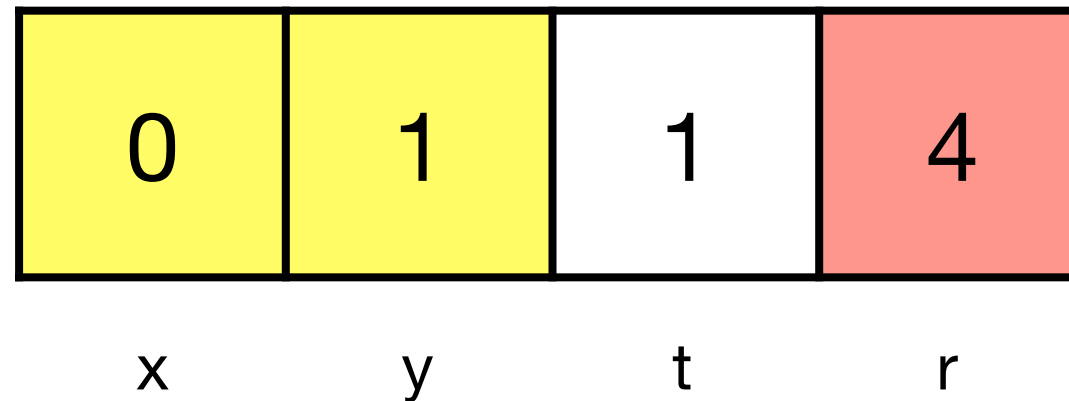
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



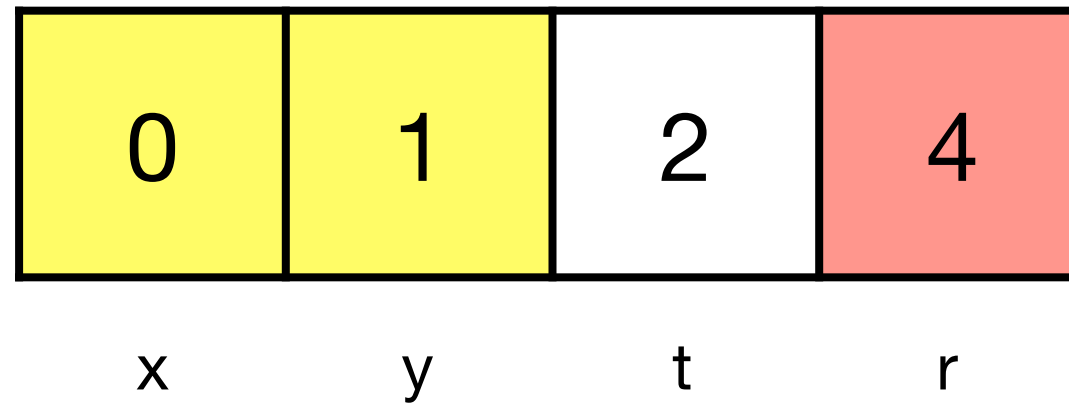
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



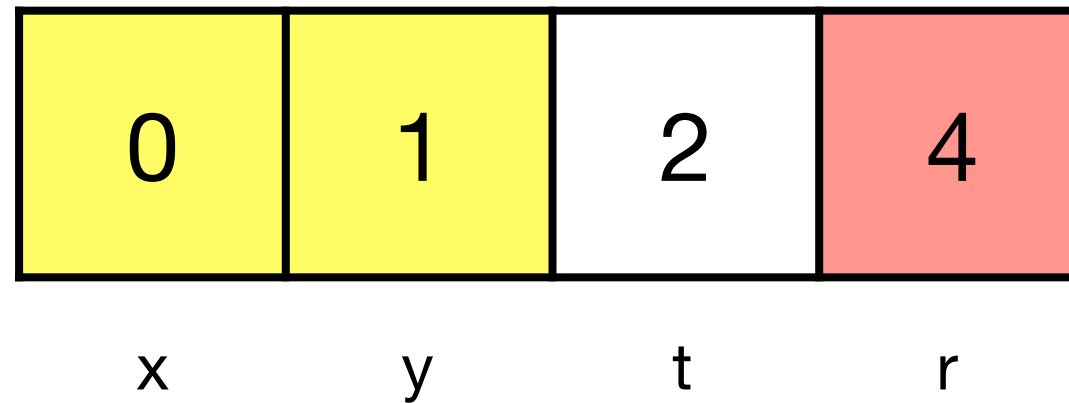
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



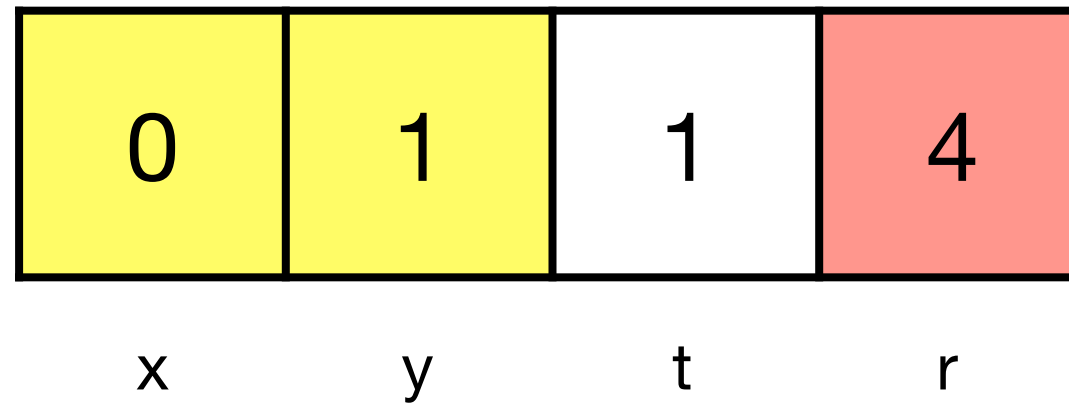
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



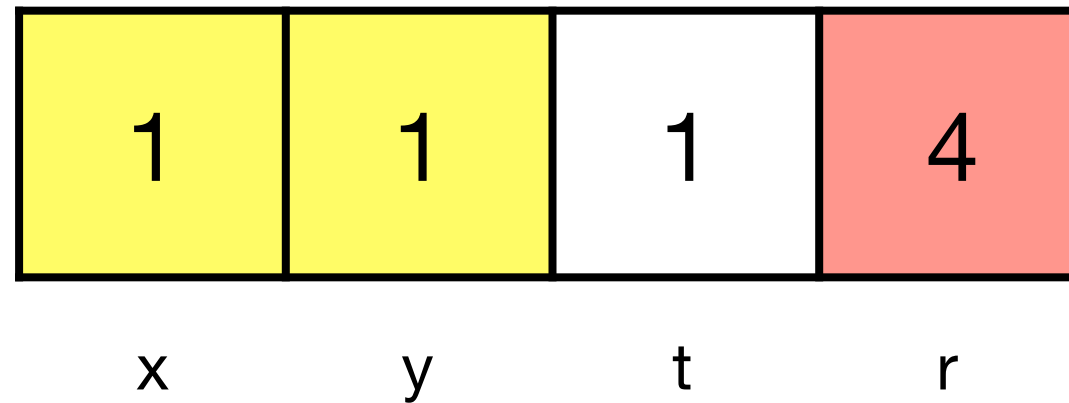
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



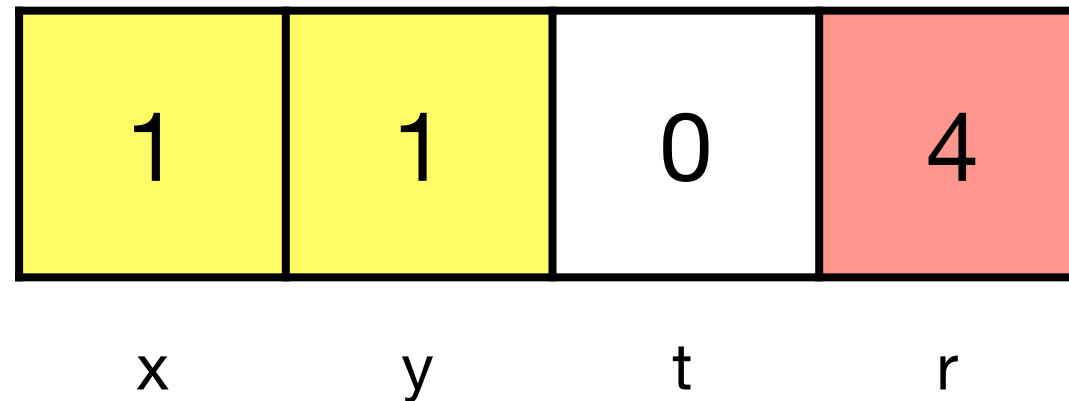
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



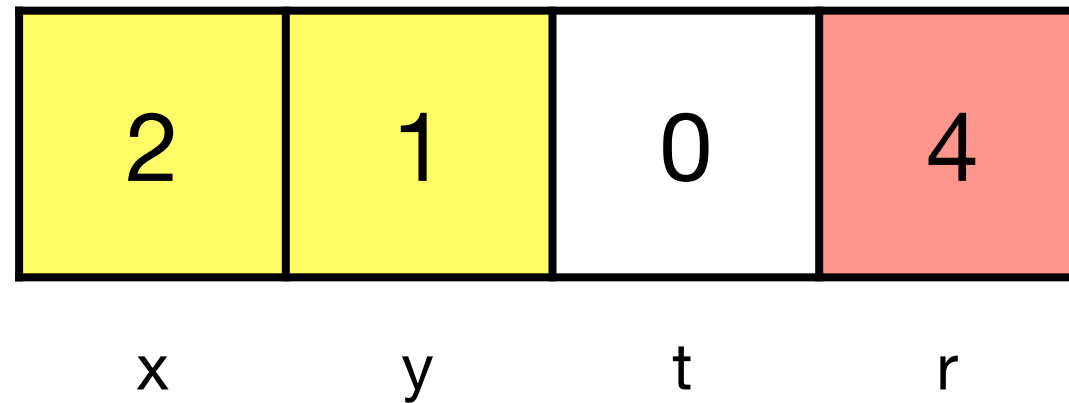
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



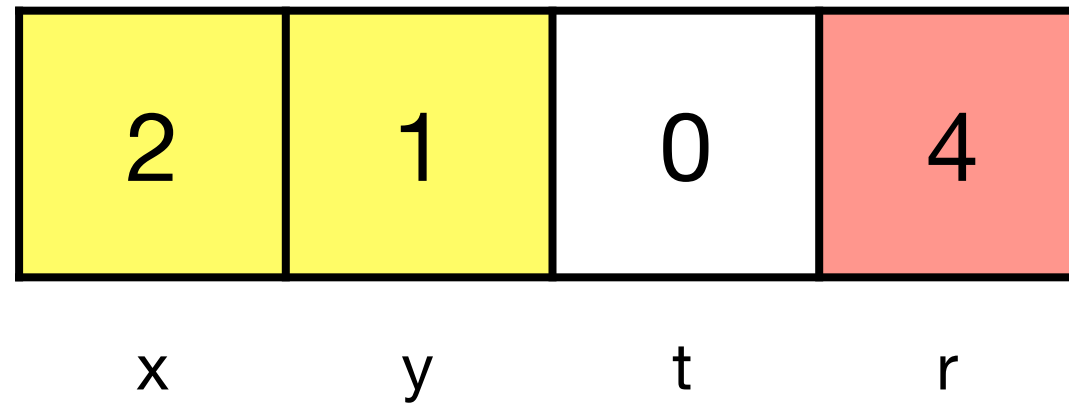
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



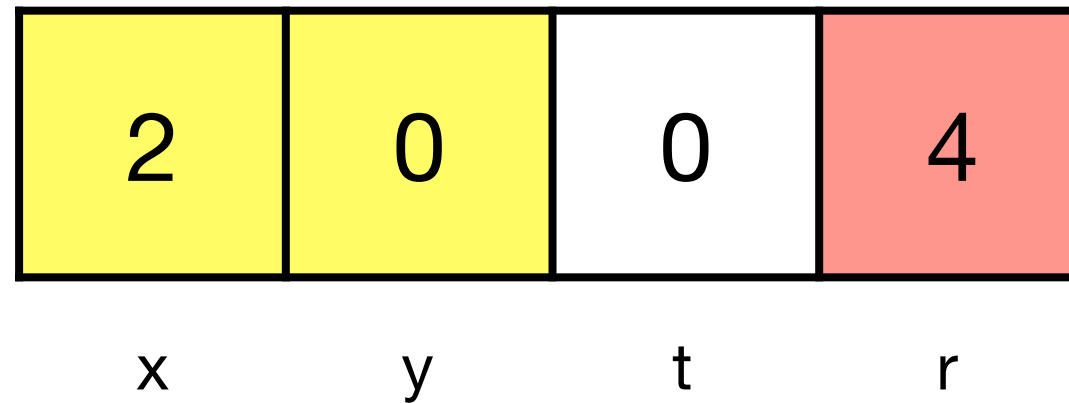
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



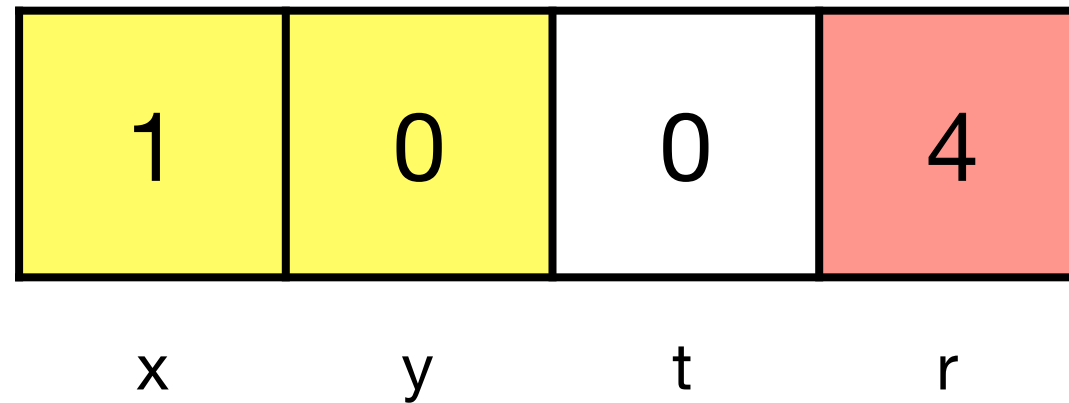
- 👉 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



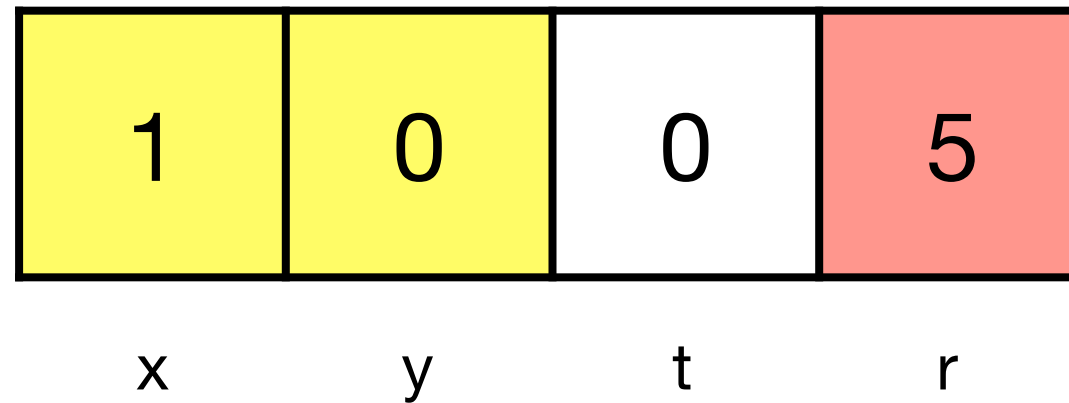
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



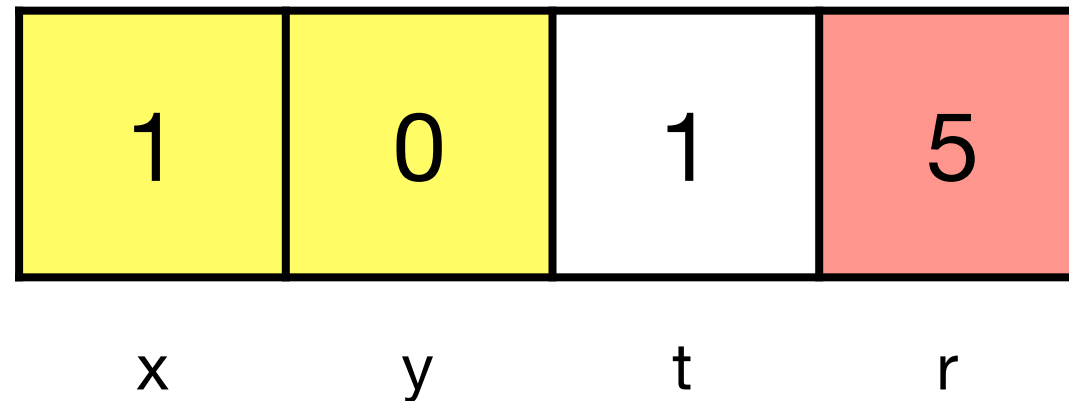
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



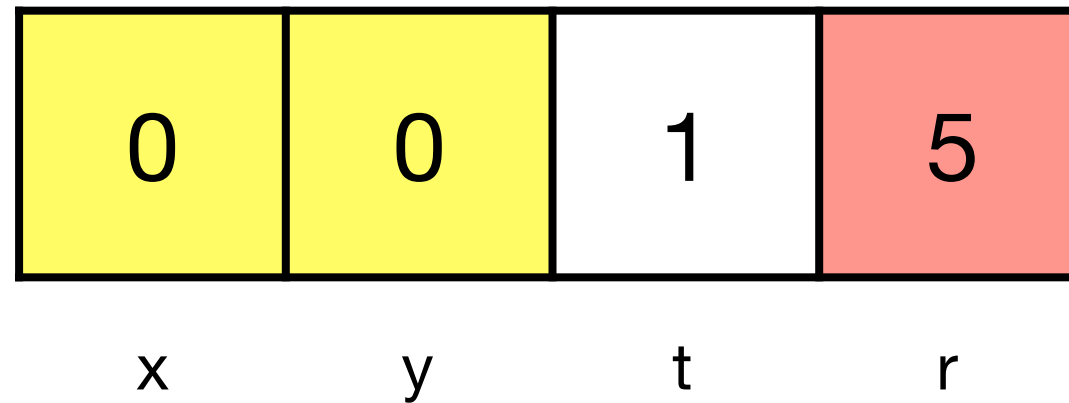
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



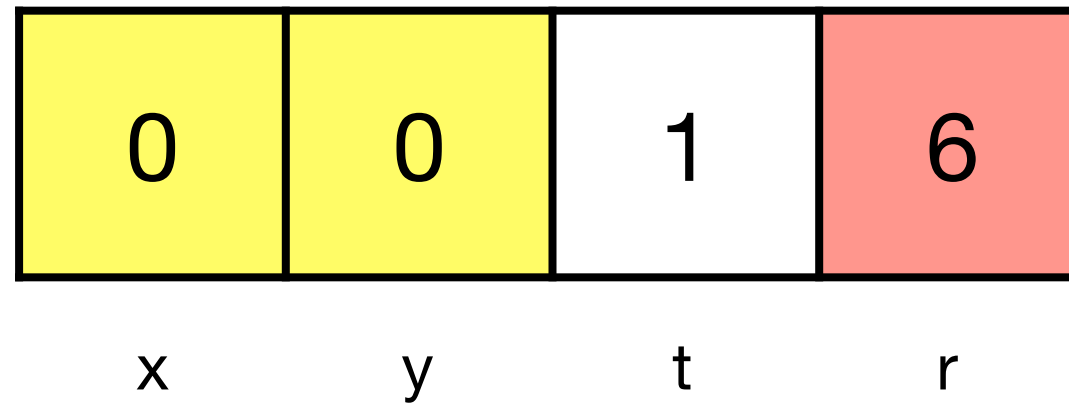
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



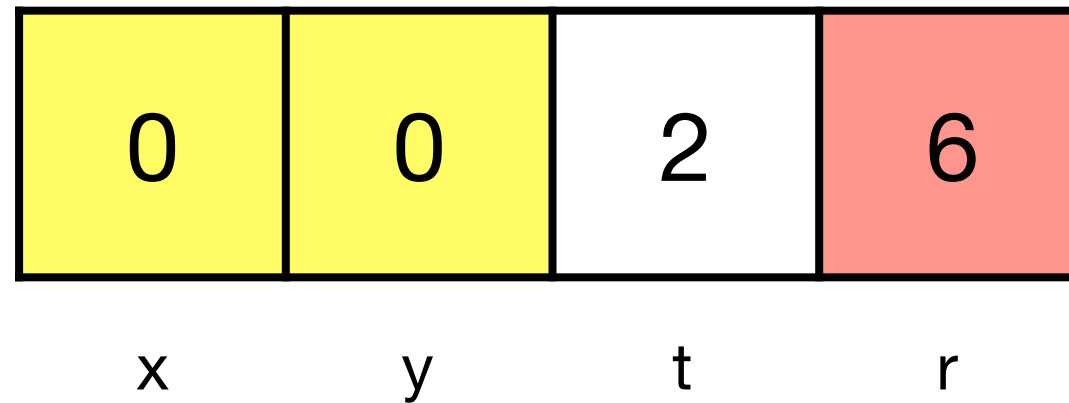
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 👉 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



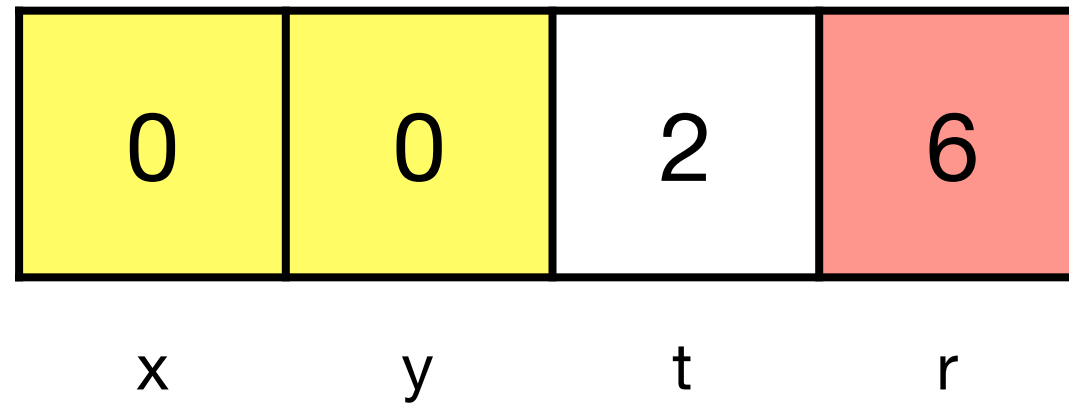
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 👉 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



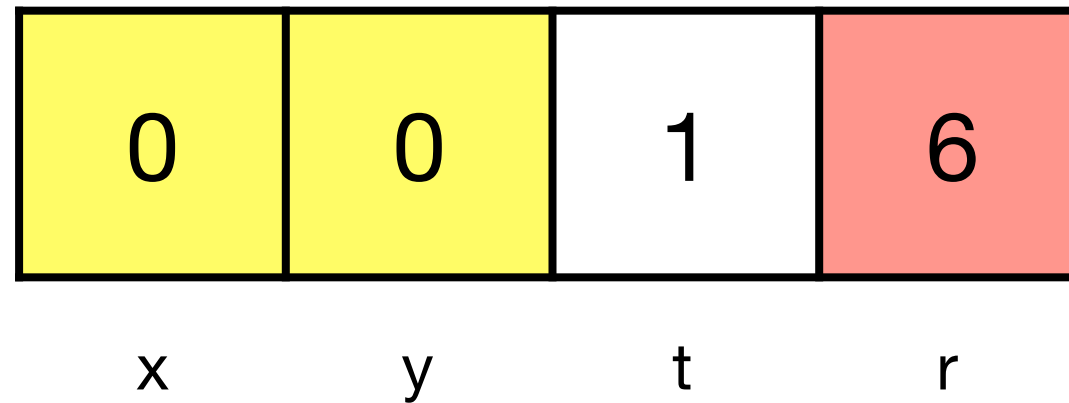
- 1: dec(y), 2, 7
- 👉 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



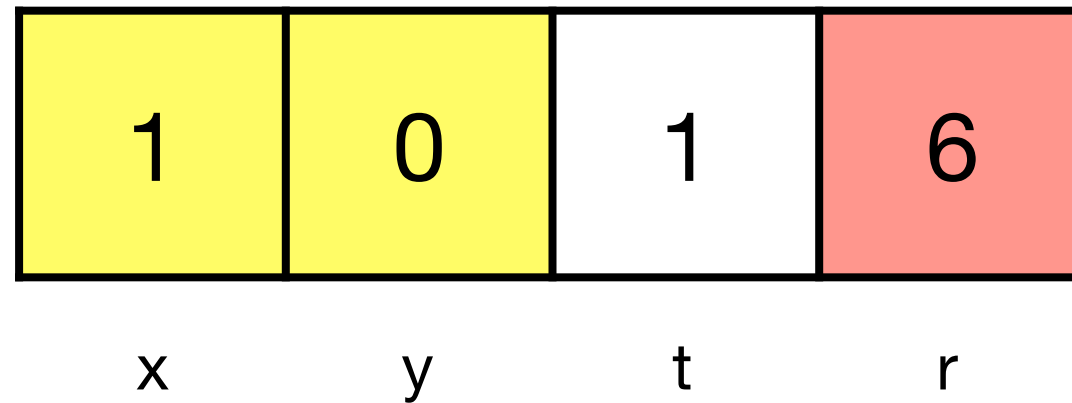
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



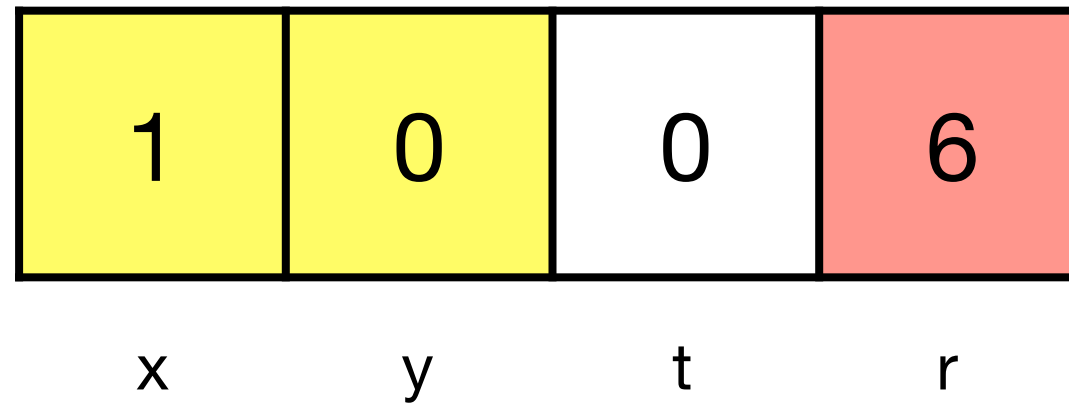
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



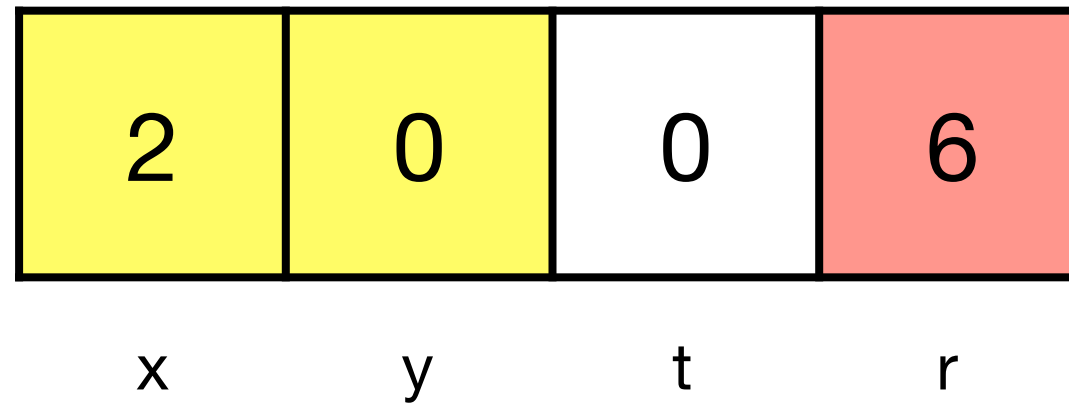
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



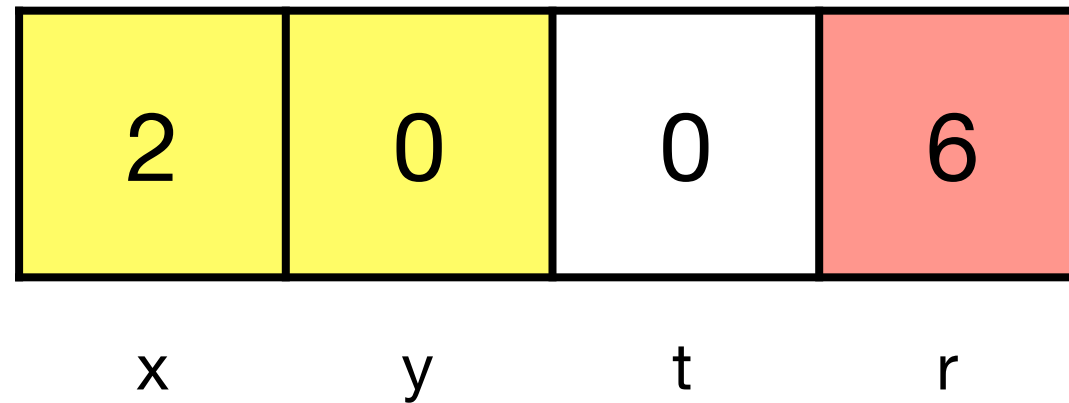
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 👉 6: inc(x), 5
- 7: stop

Machines à registres



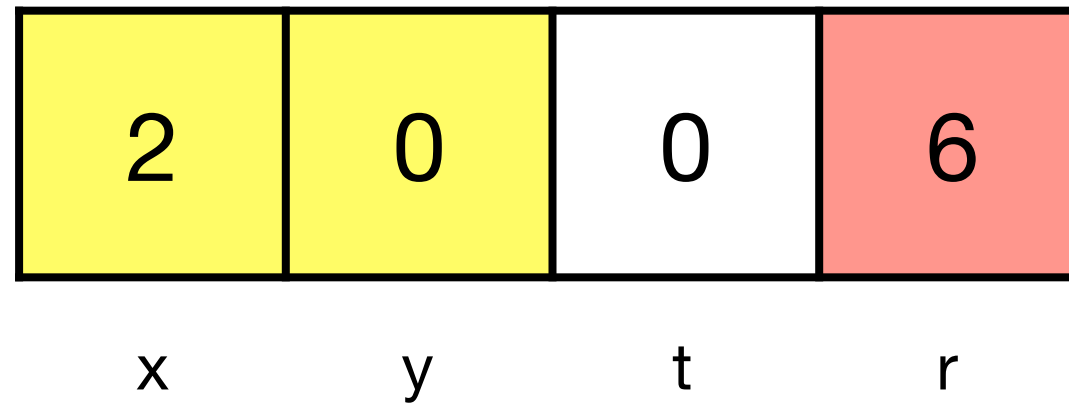
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



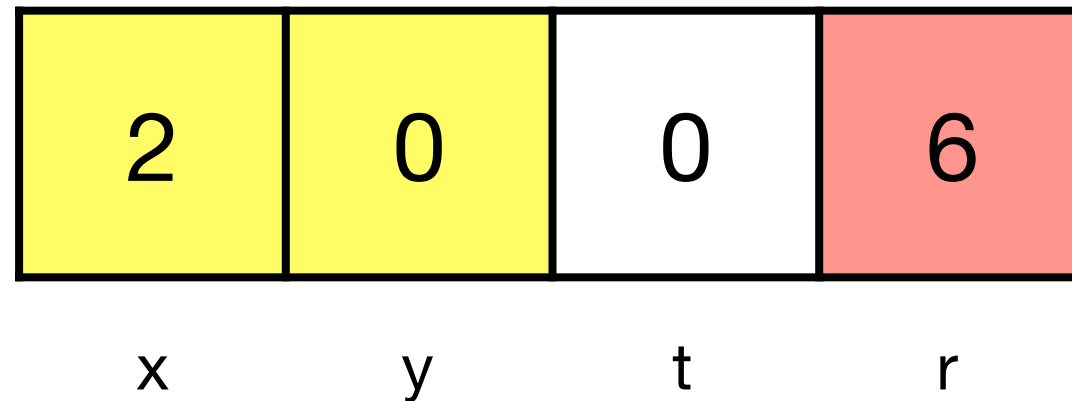
- 👉 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop

Machines à registres



- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 👉 7: stop

Machines à registres



1: dec(y), 2, 7

2: dec(x), 3, 5

3: inc(r), 4

4: inc(t), 2

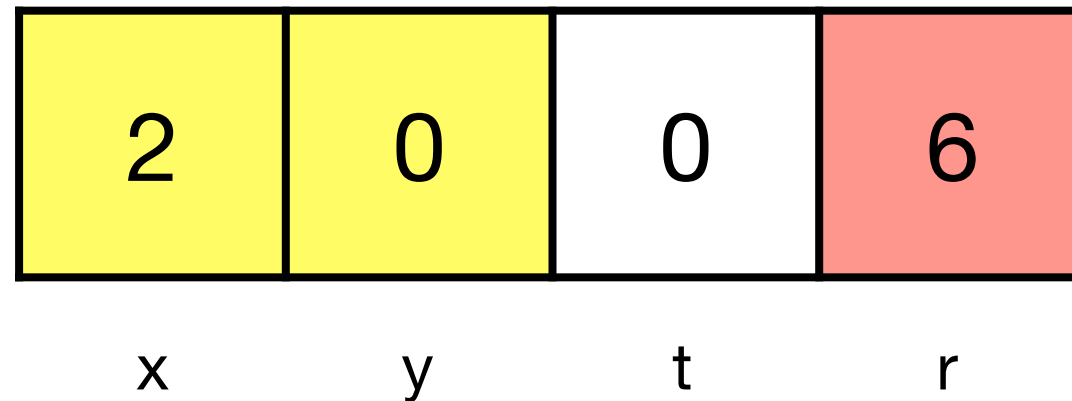
5: dec(t), 6, 1

6: inc(x), 5

👉 7: stop

**qu'est-ce
qu'on a
calculé ?**

Machines à registres

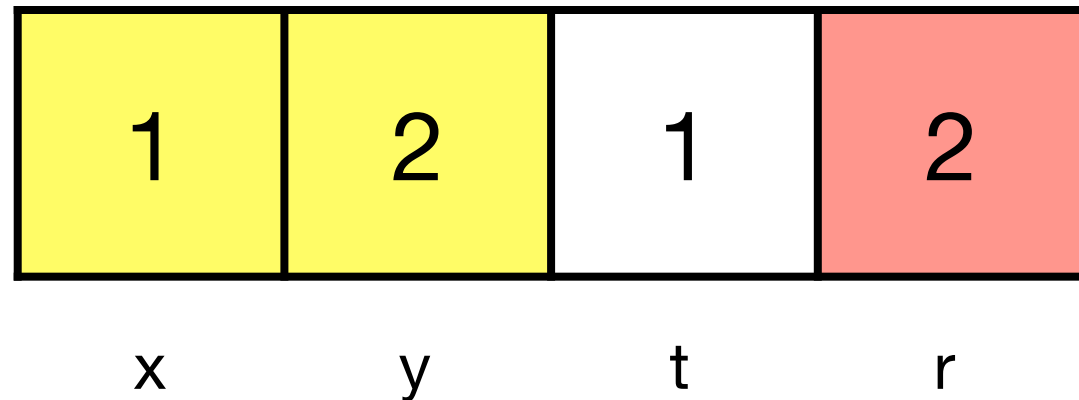


- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 5: dec(t), 6, 1
- 6: inc(x), 5
- 👉 7: stop

**le produit
des valeurs
initiales
de x et y**

**Les réactions chimiques
sont universelles**

Config. machine → balloon



1: dec(y), 2, 7

2: dec(x), 3, 5

3: inc(r), 4

4: inc(t), 2

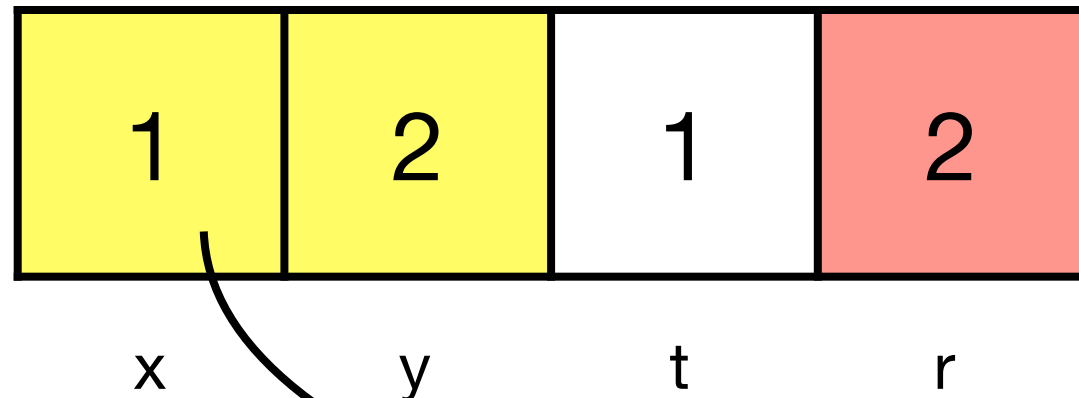
👉 5: dec(t), 6, 1

6: inc(x), 5

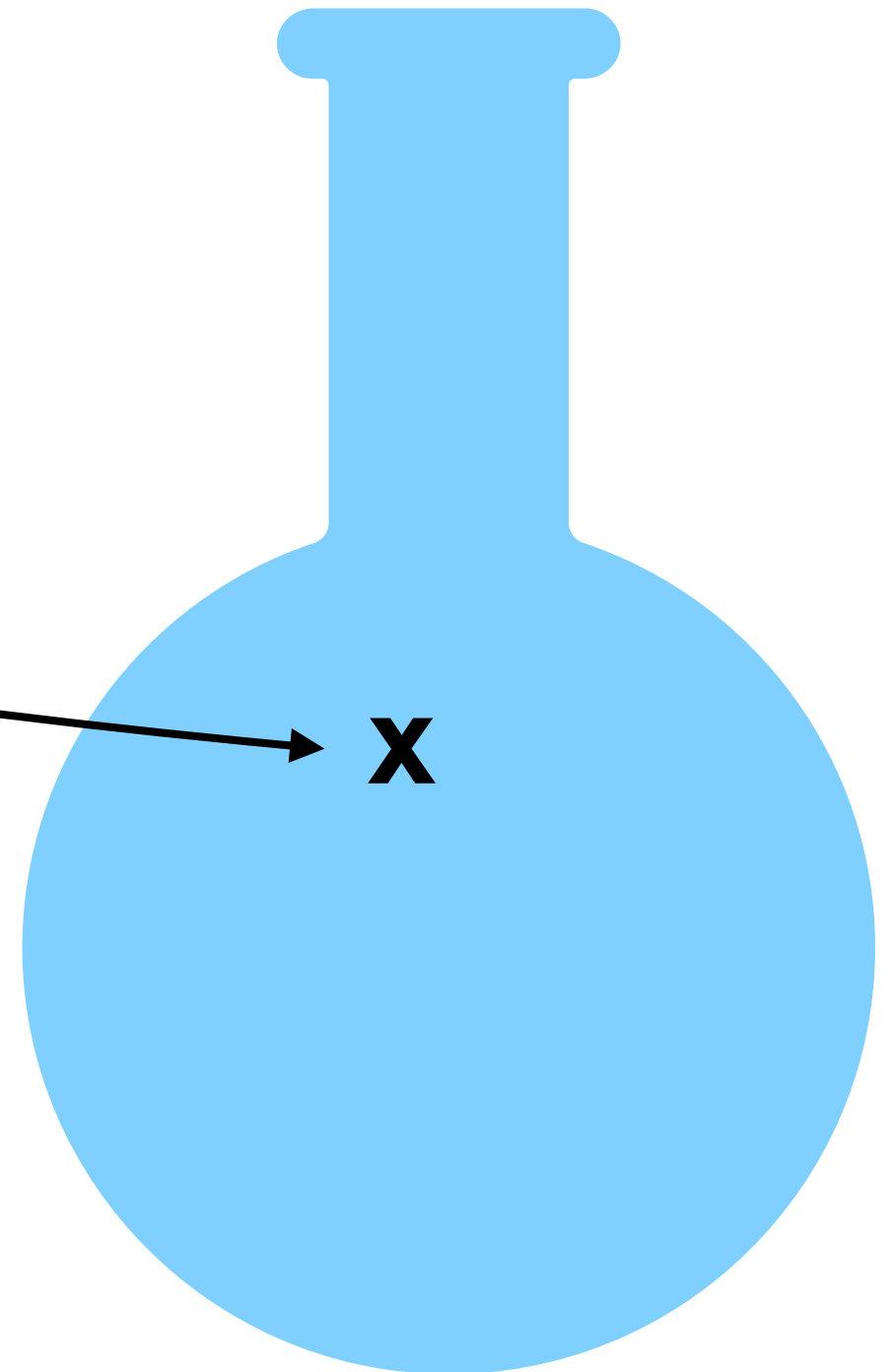
7: stop



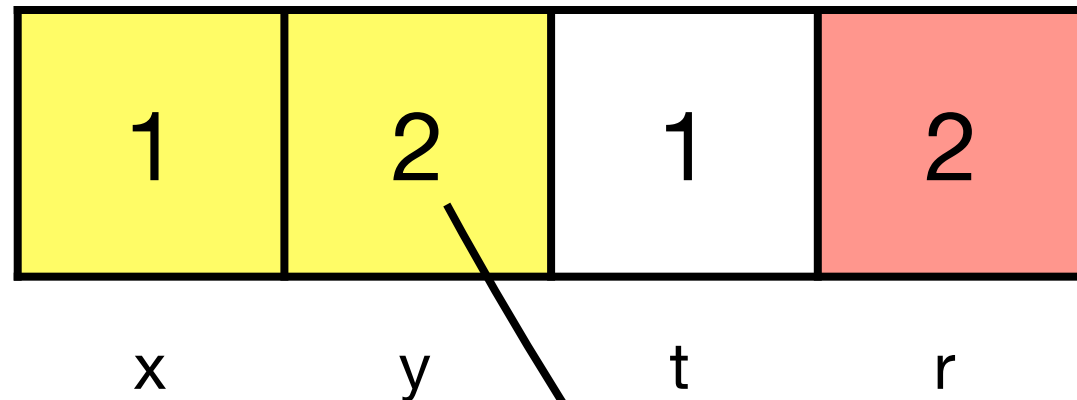
Config. machine \rightarrow balloon



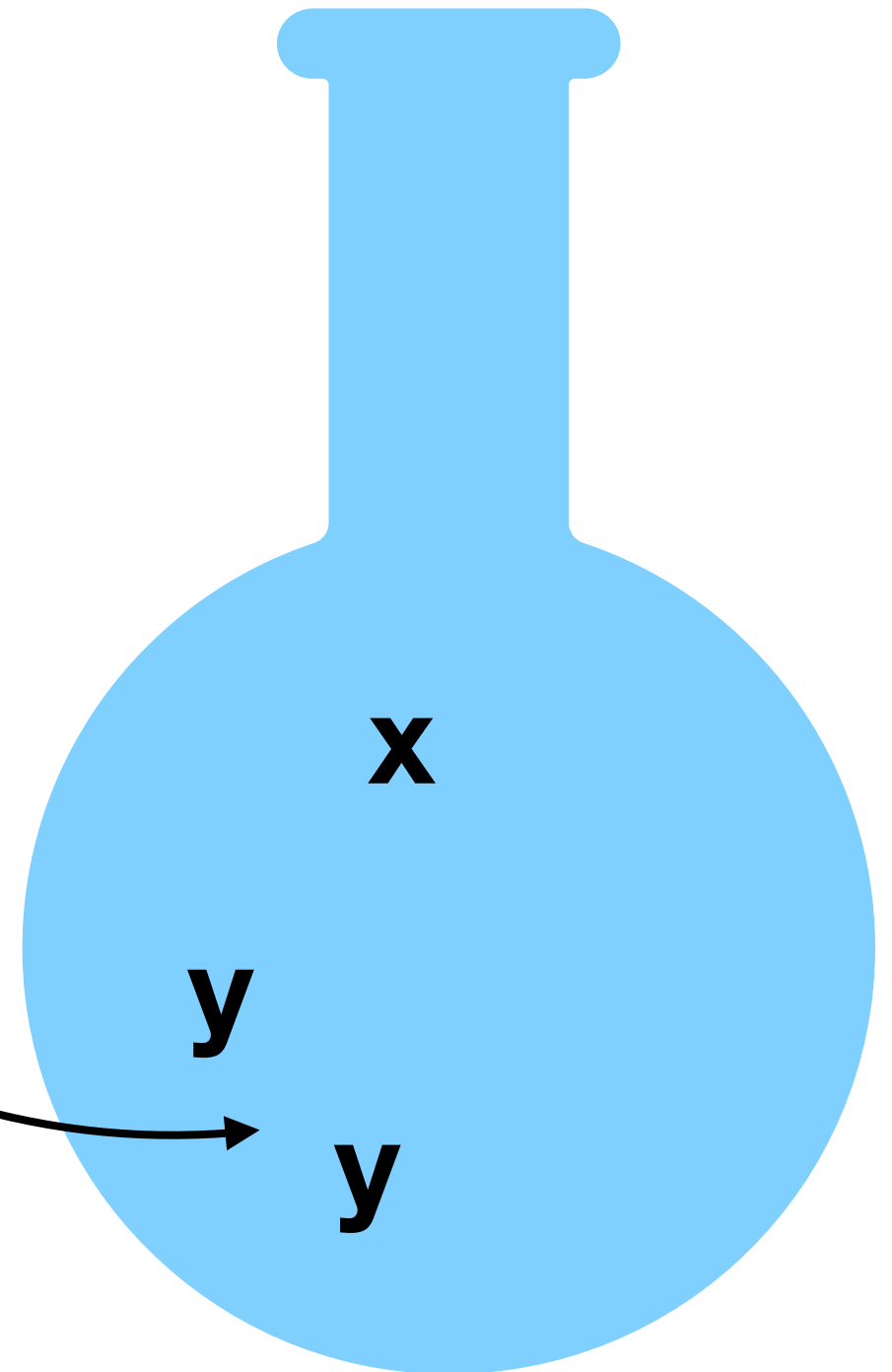
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



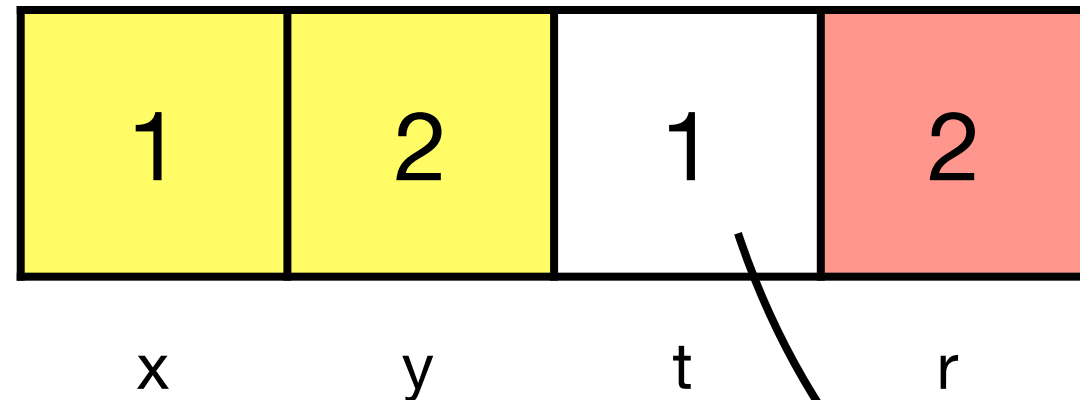
Config. machine \rightarrow balloon



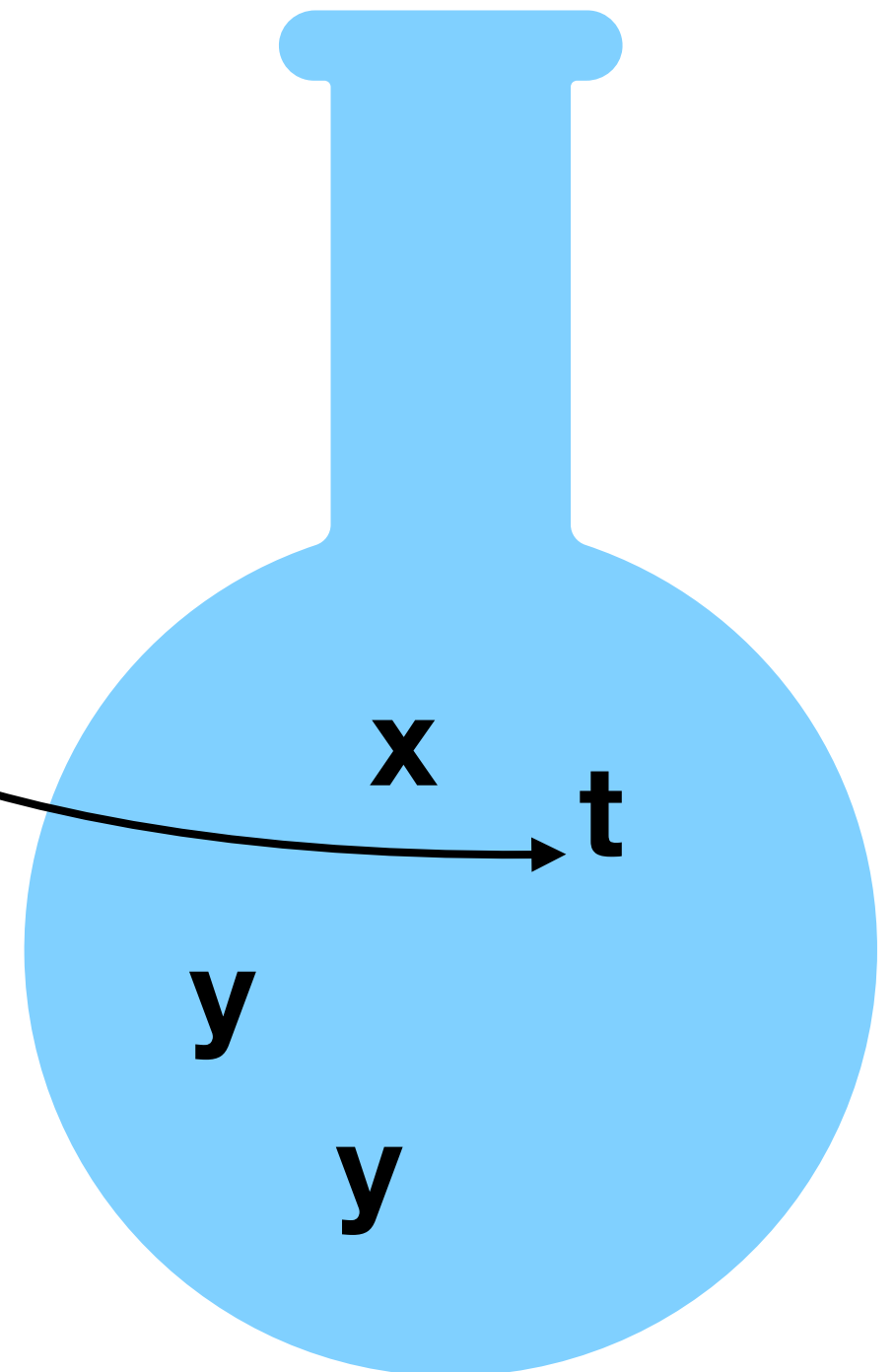
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



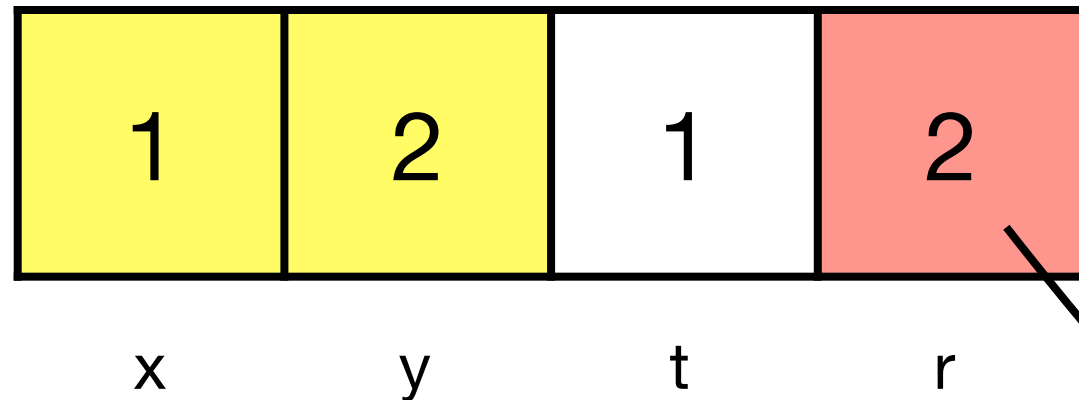
Config. machine \rightarrow balloon



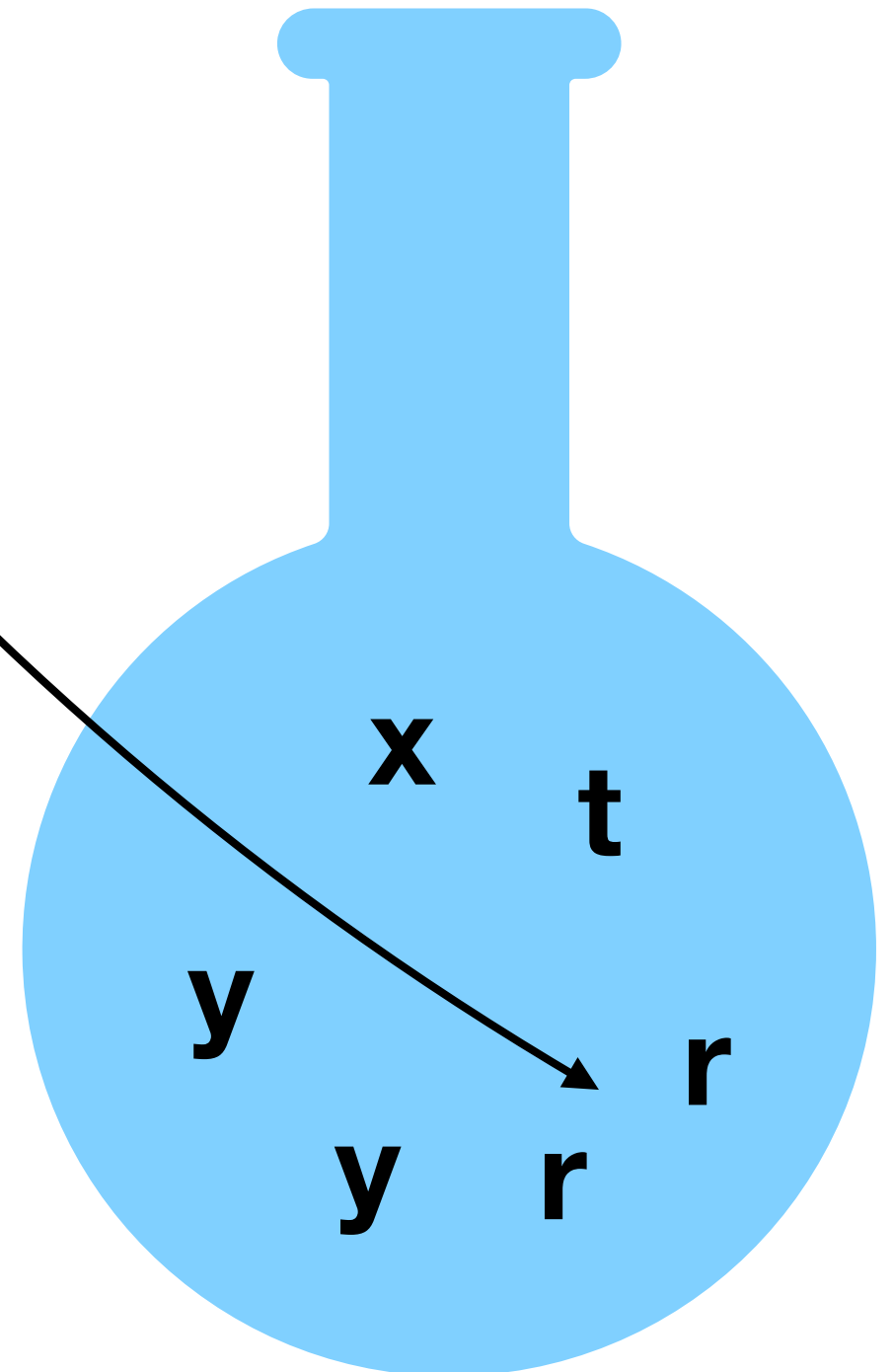
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



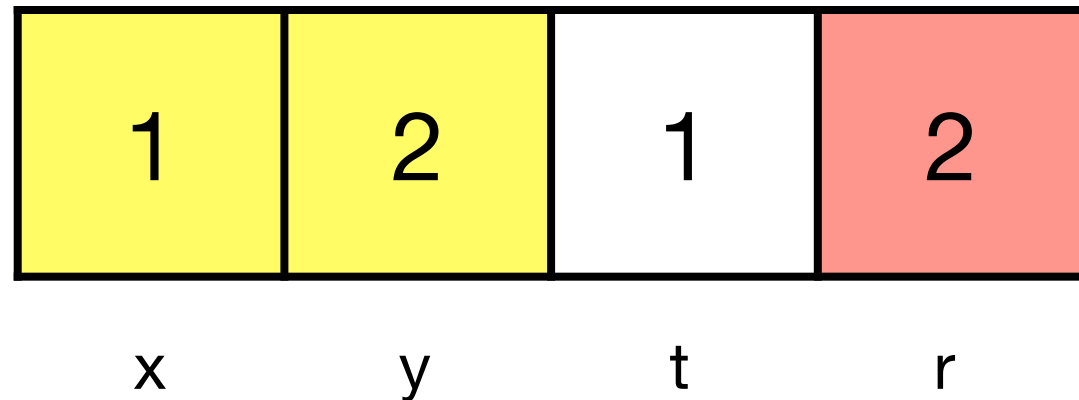
Config. machine → balloon



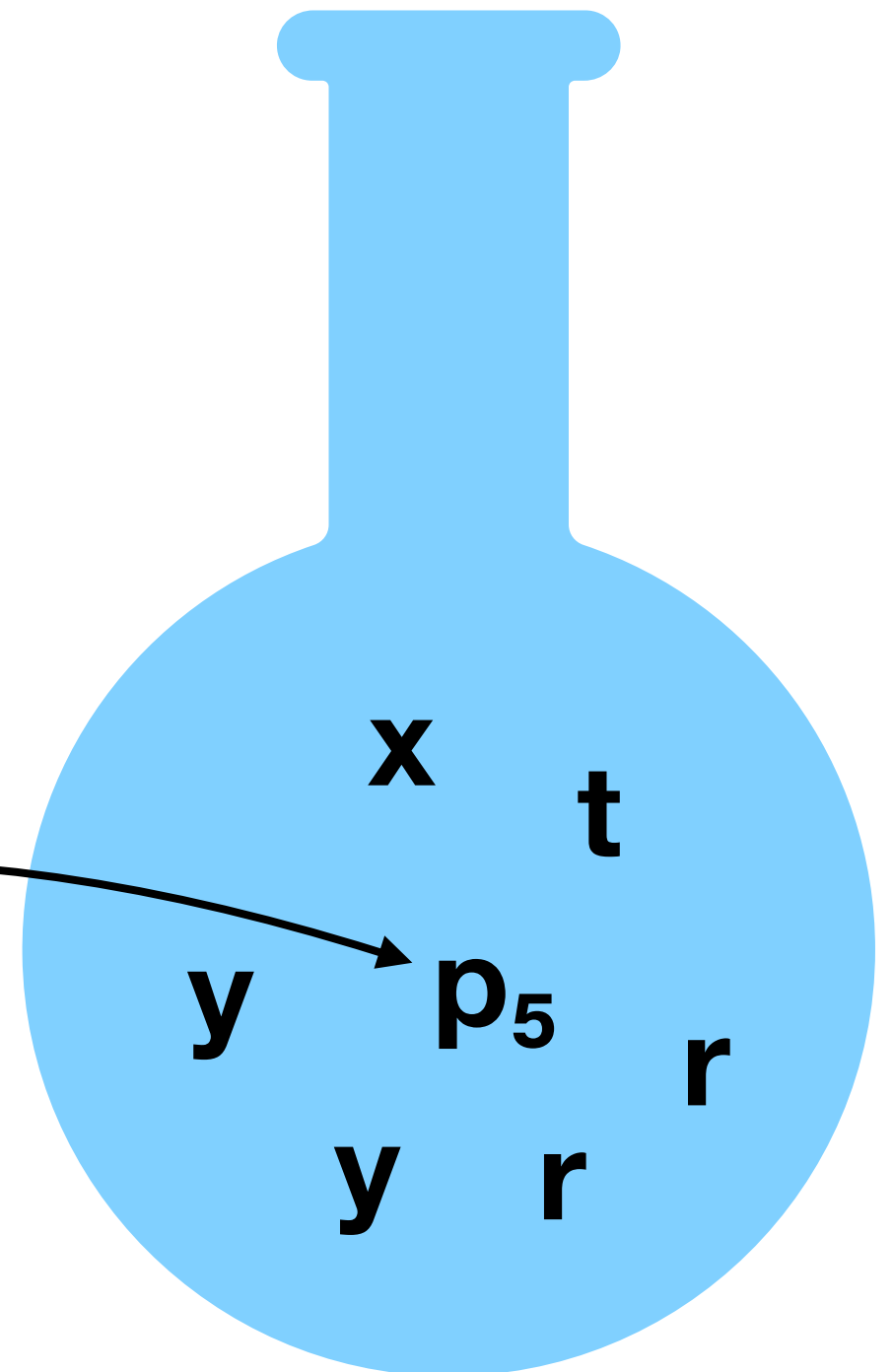
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



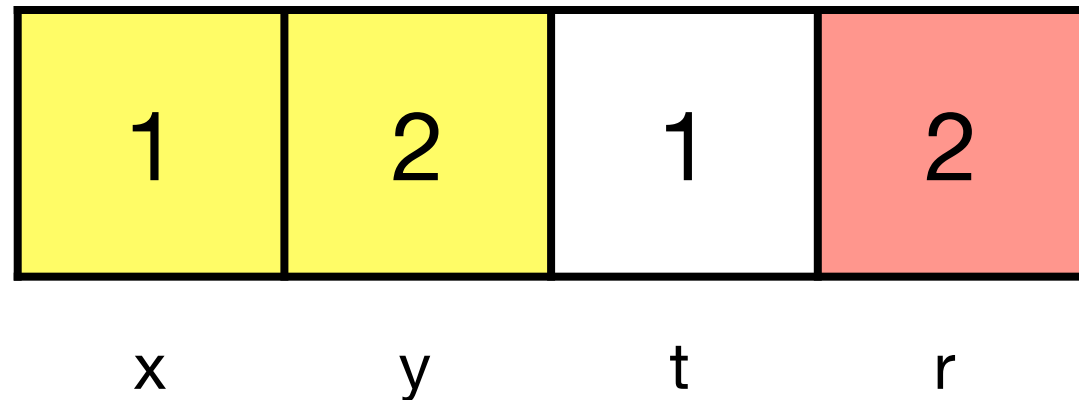
Config. machine \rightarrow balloon



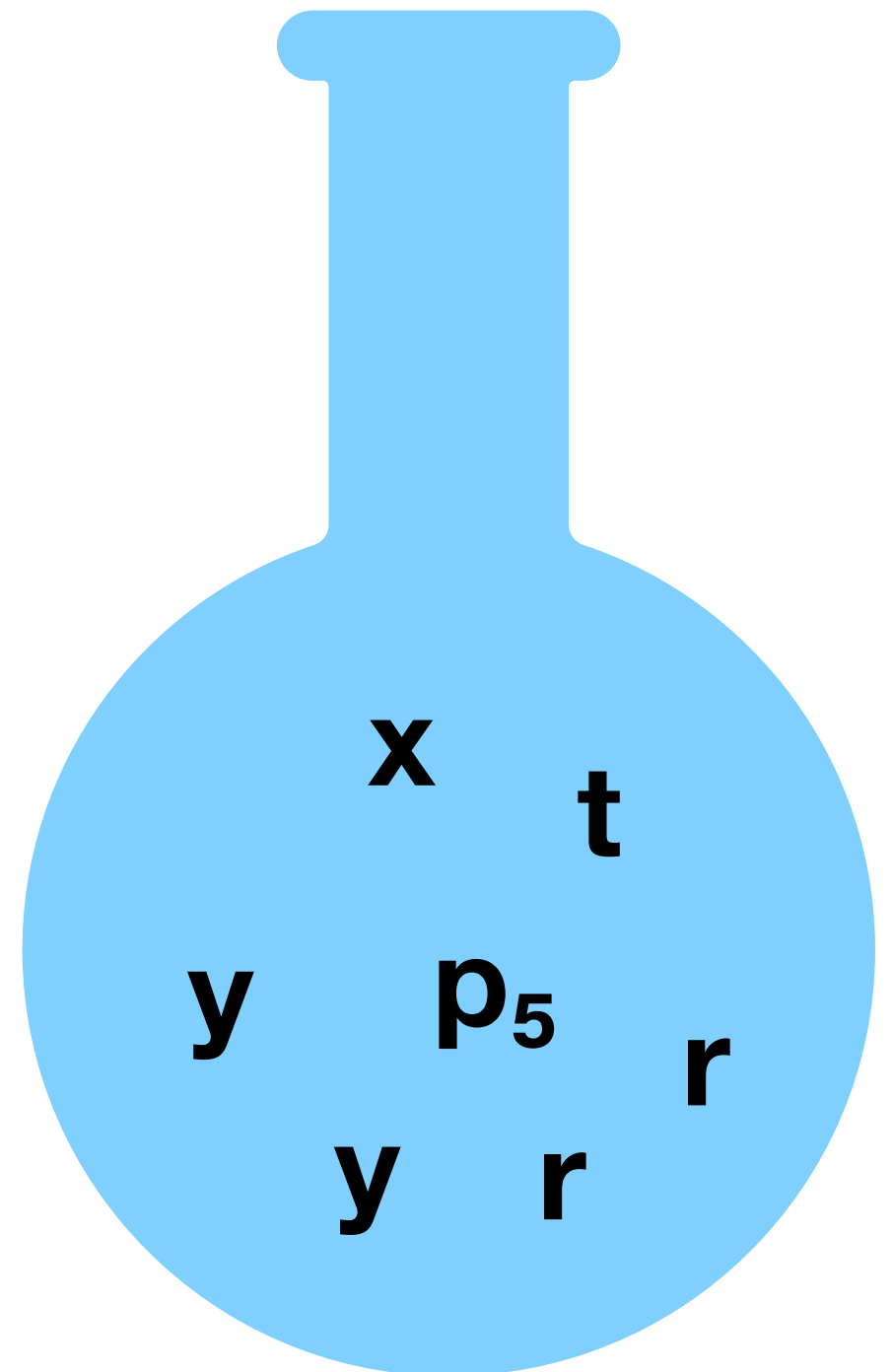
- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



Config. machine \rightarrow balloon



- 1: dec(y), 2, 7
- 2: dec(x), 3, 5
- 3: inc(r), 4
- 4: inc(t), 2
- 👉 5: dec(t), 6, 1
- 6: inc(x), 5
- 7: stop



Instructions → réactions

3: inc(r), 4

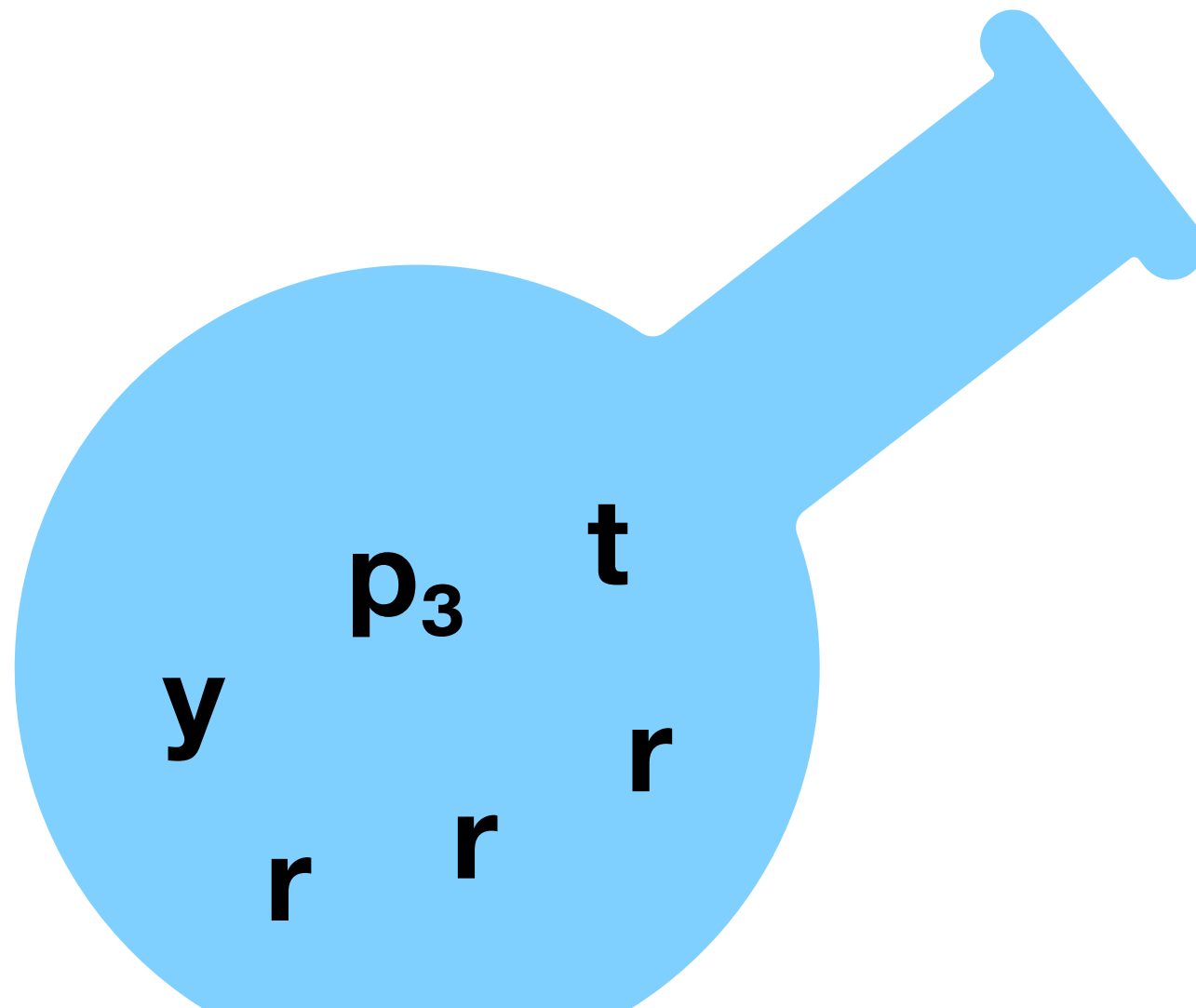
Instructions → réactions

3: inc(r), 4



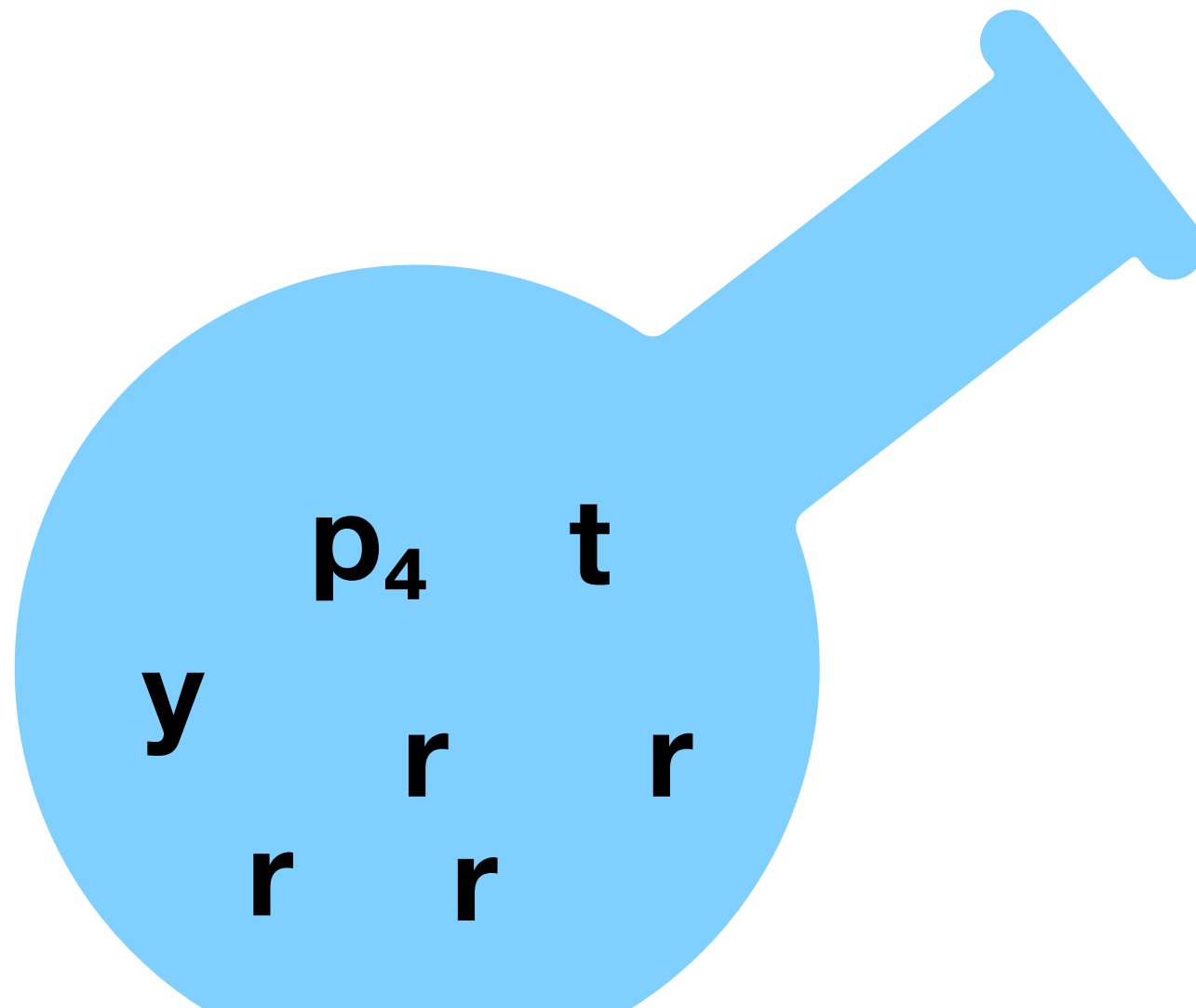
Instructions → réactions

3: inc(r), 4



Instructions → réactions

3: inc(r), 4

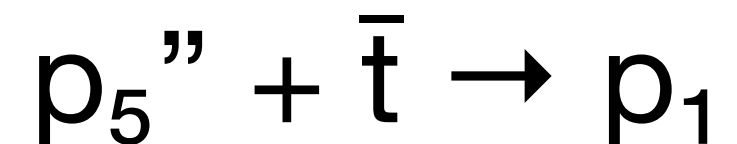
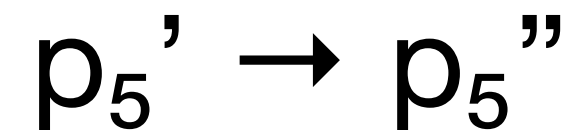
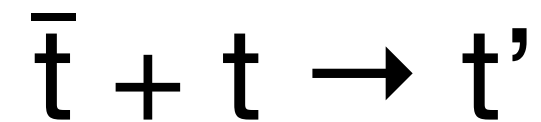


Instructions → réactions

5: dec(t), 6, 1

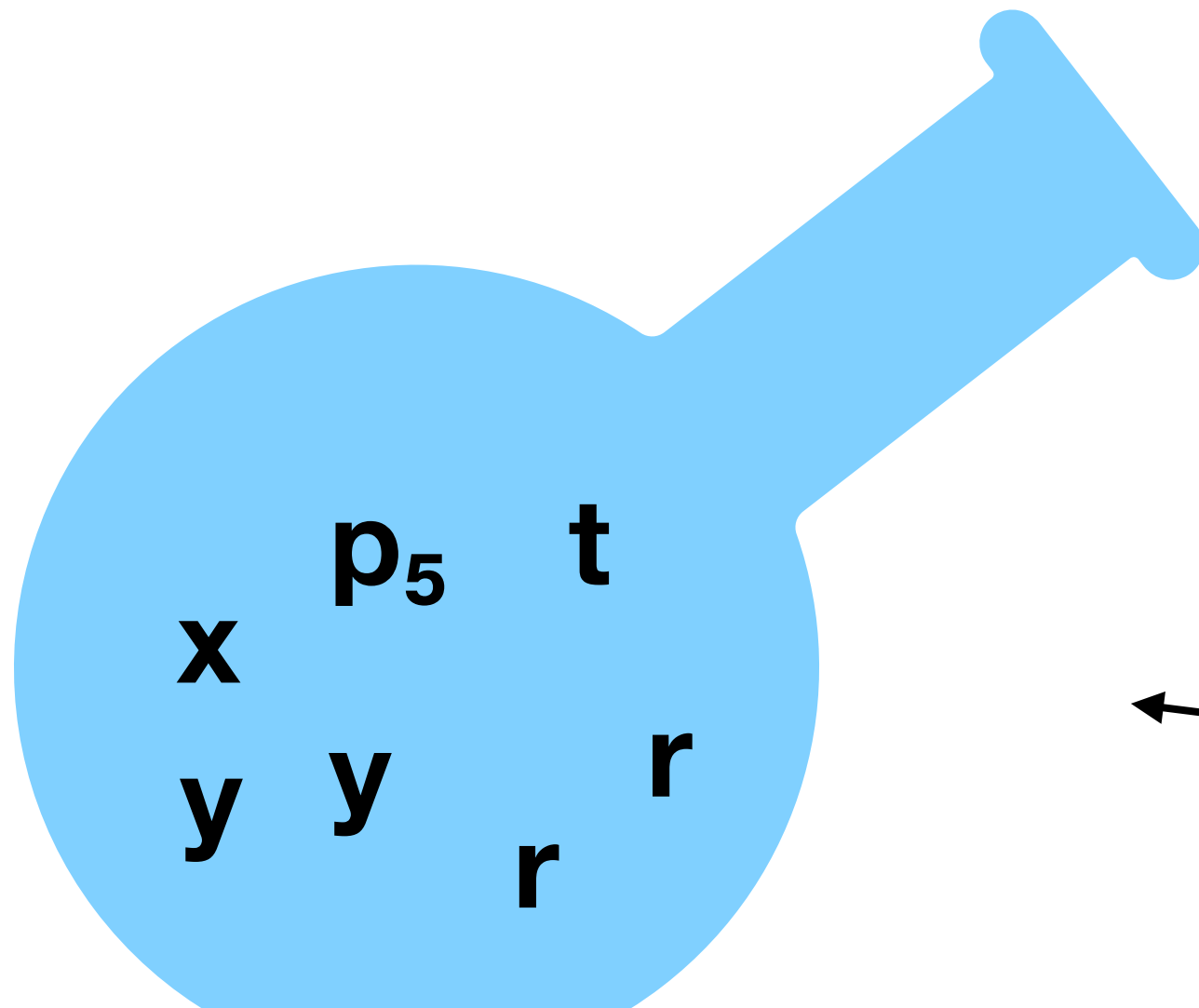
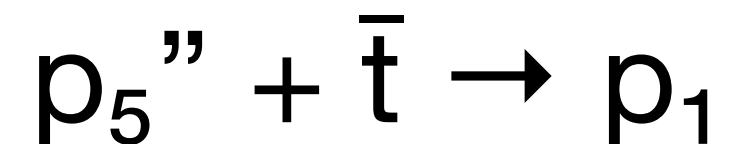
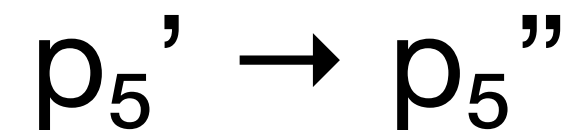
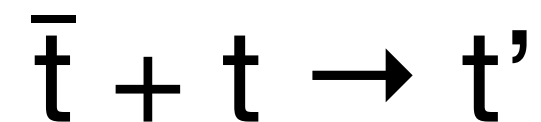
Instructions \rightarrow réactions

5: dec(t), 6, 1



Instructions → réactions

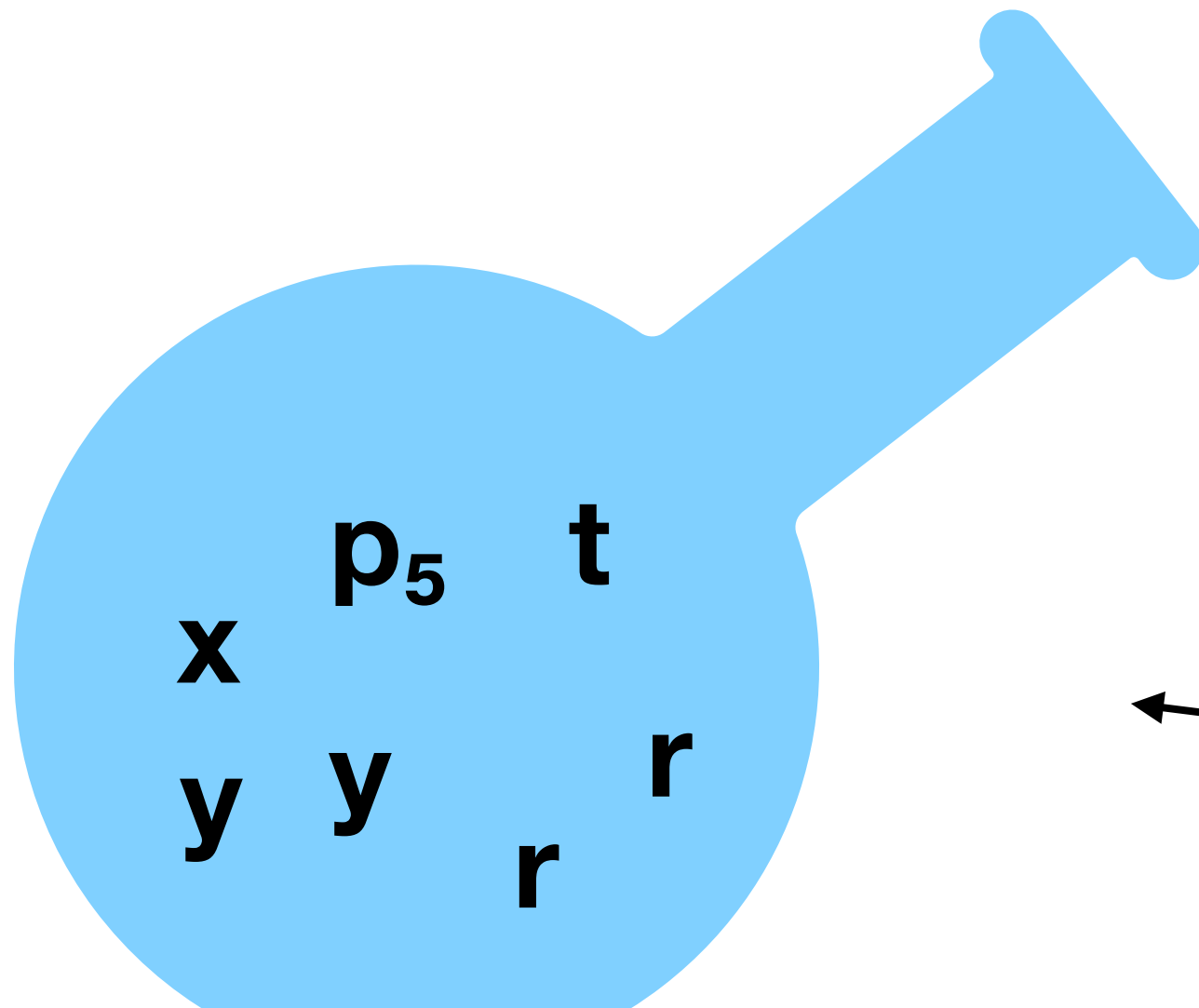
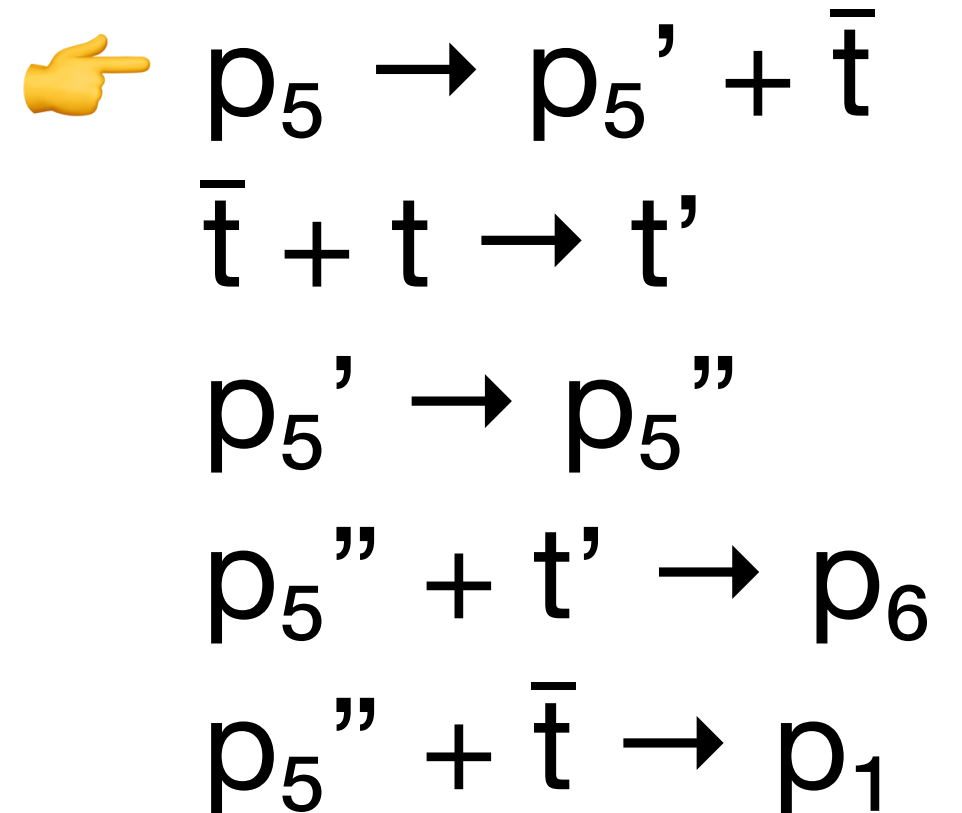
5: dec(t), 6, 1



← s'il y a au moins un t

Instructions → réactions

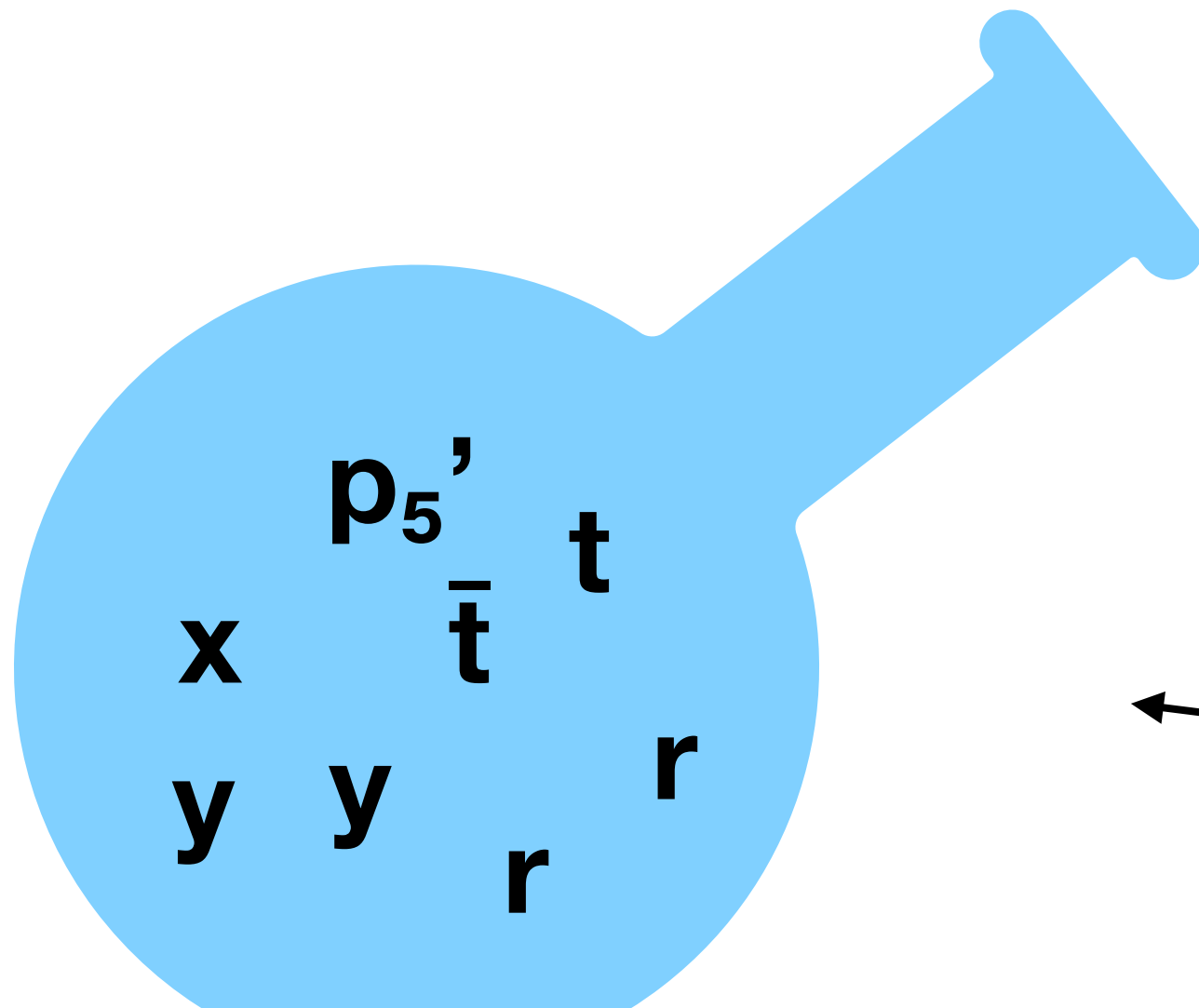
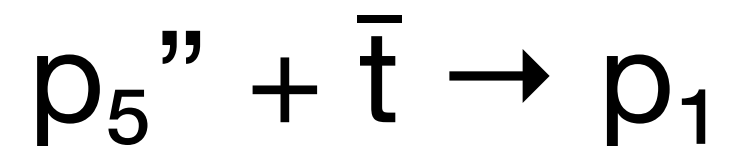
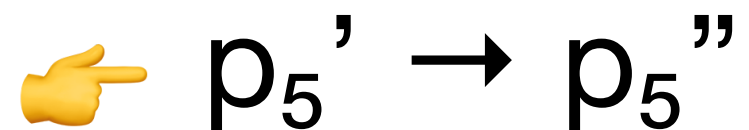
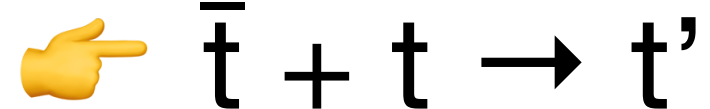
5: dec(t), 6, 1



← s'il y a au moins un t

Instructions → réactions

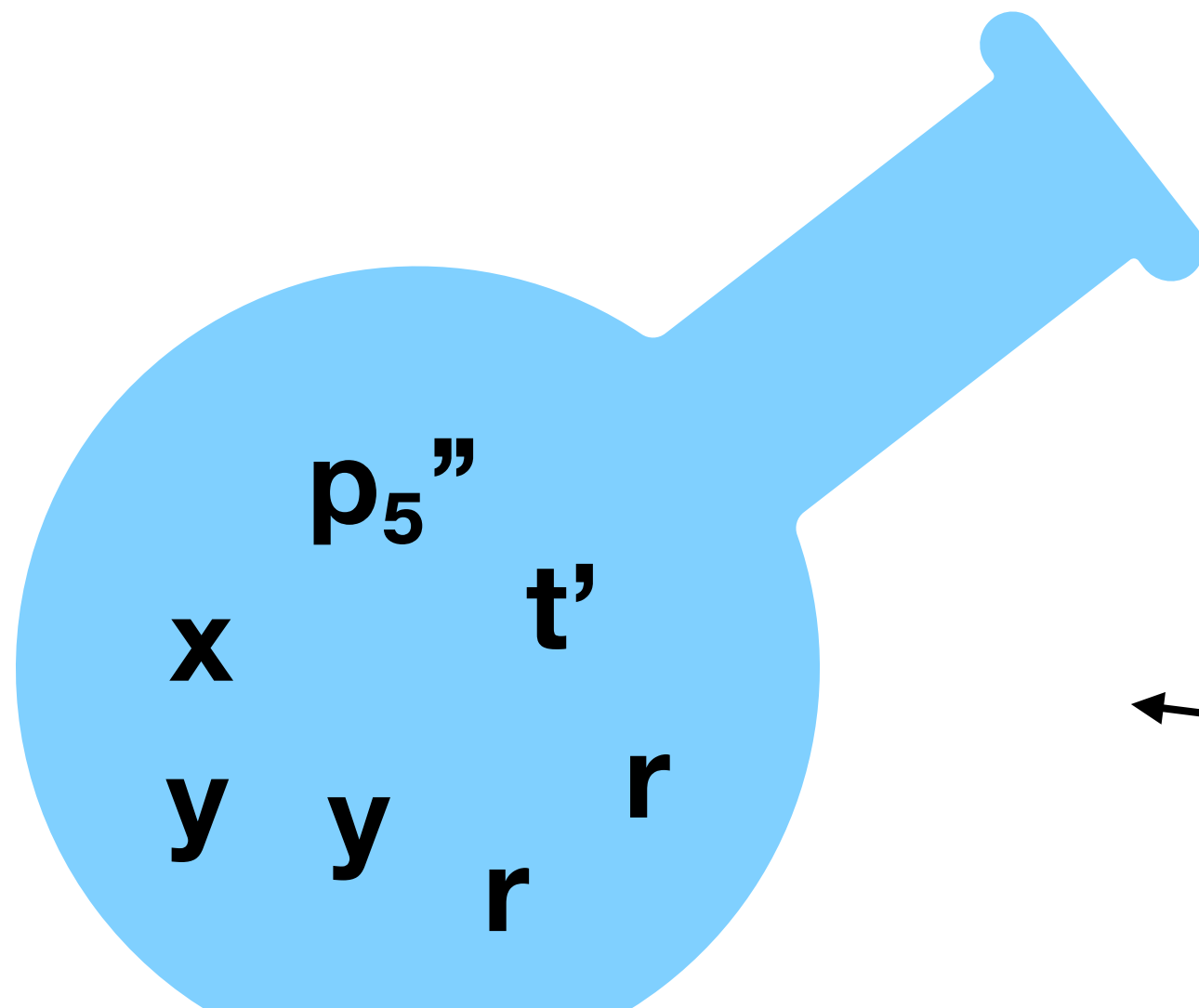
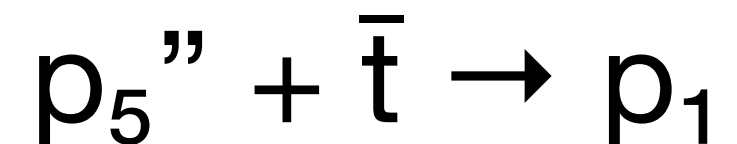
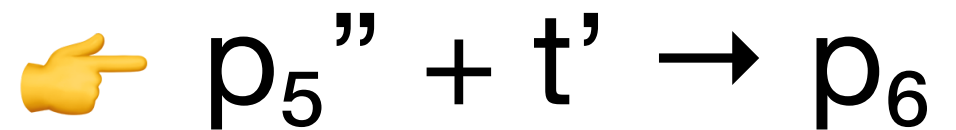
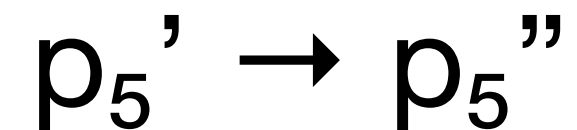
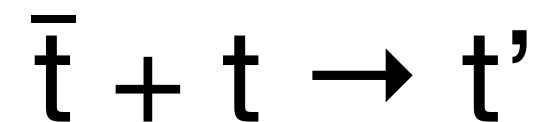
5: dec(t), 6, 1



← s'il y a au moins un t

Instructions → réactions

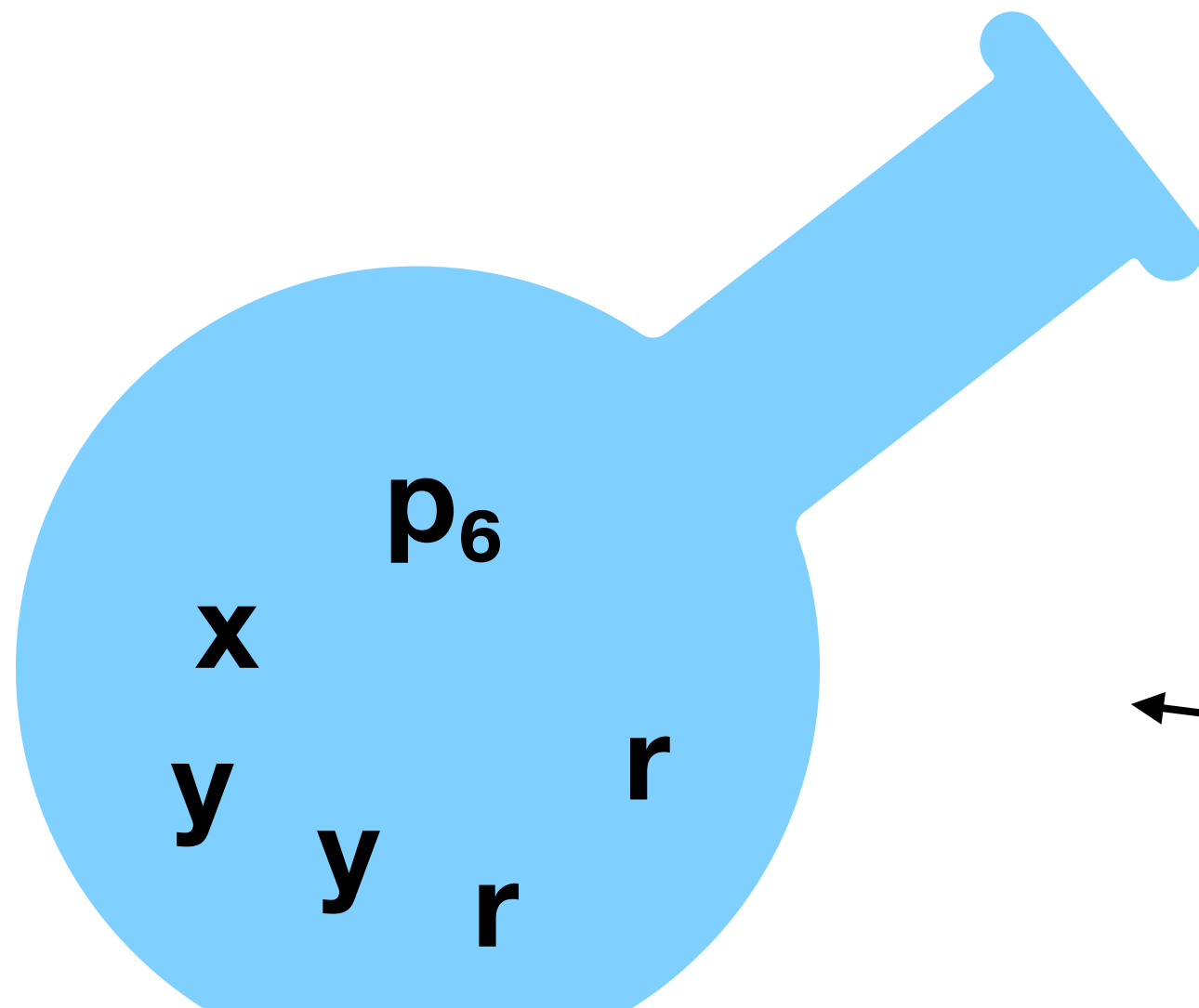
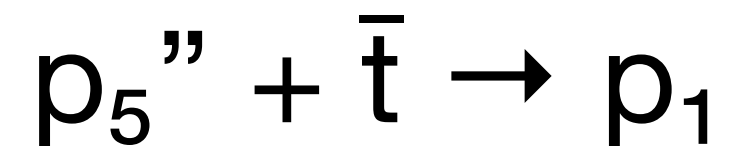
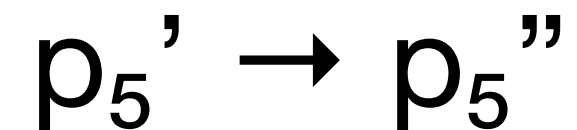
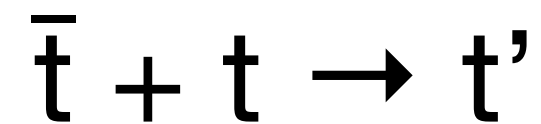
5: dec(t), 6, 1



← s'il y a au moins un t

Instructions → réactions

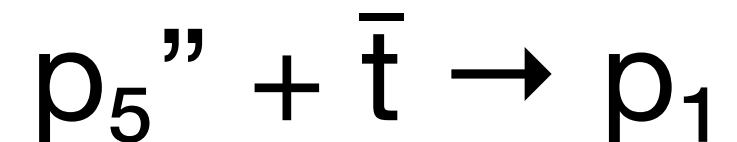
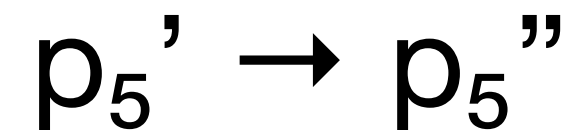
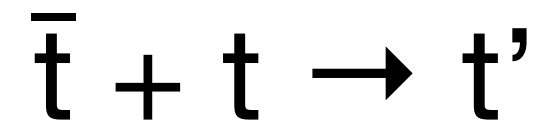
5: dec(t), 6, 1



← s'il y a au moins un t

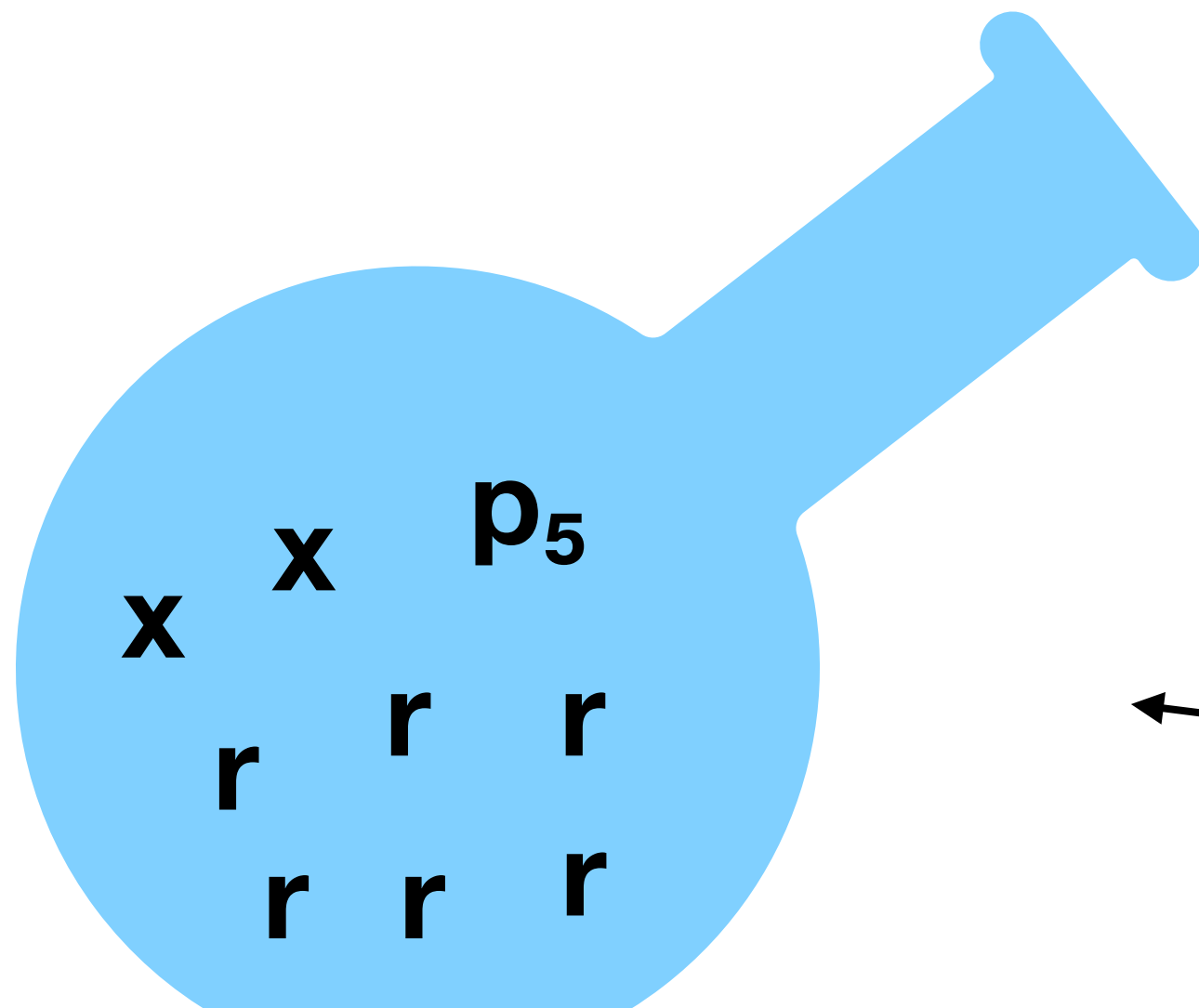
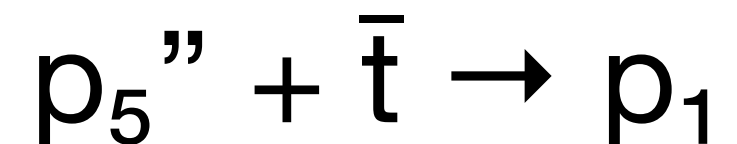
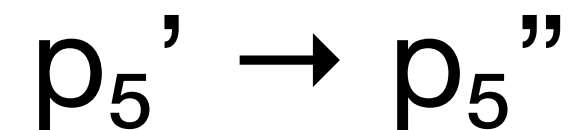
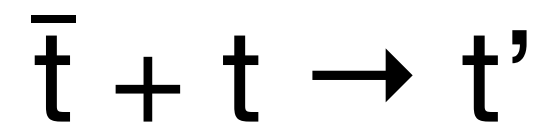
Instructions → réactions

5: dec(t), 6, 1



Instructions → réactions

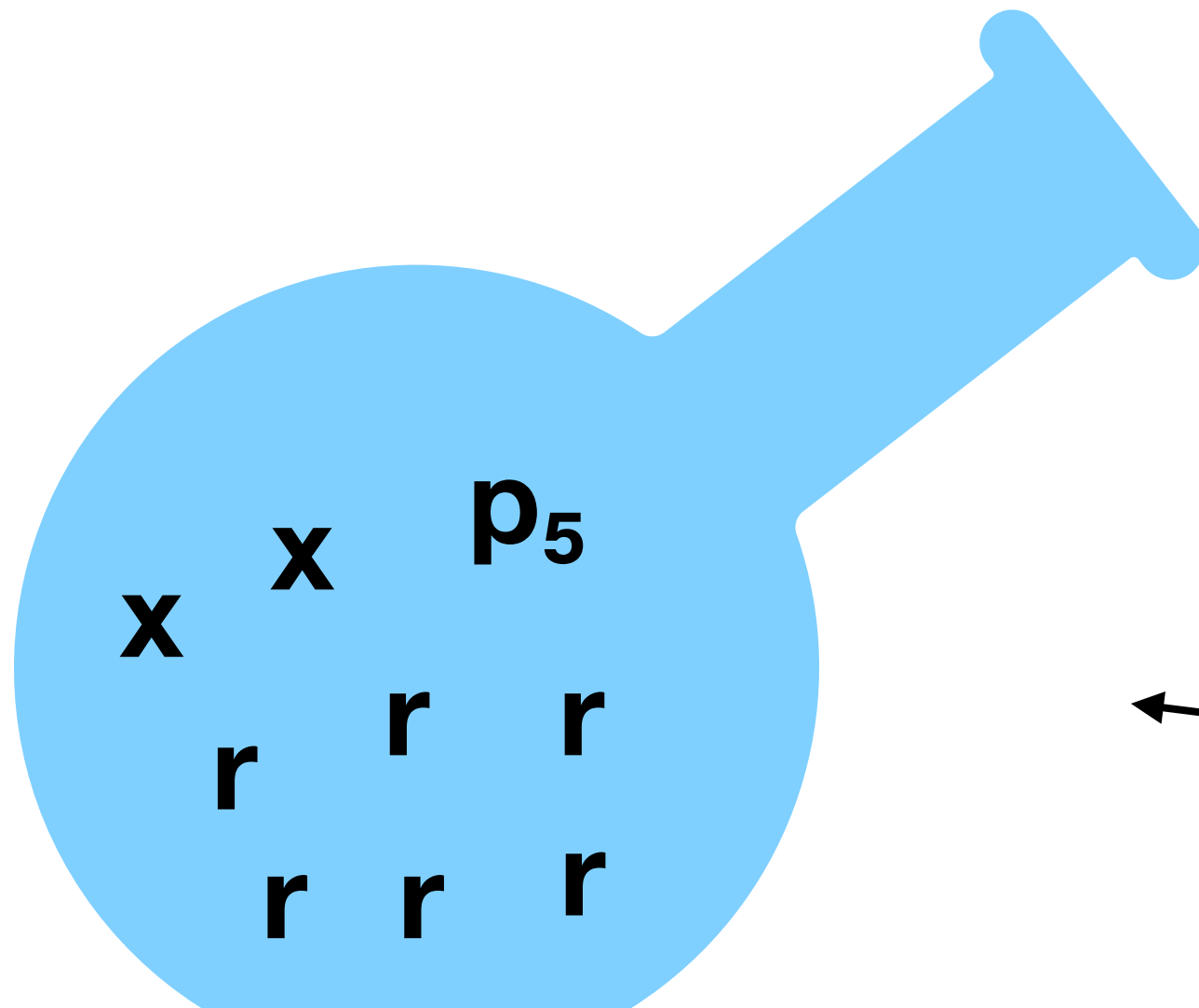
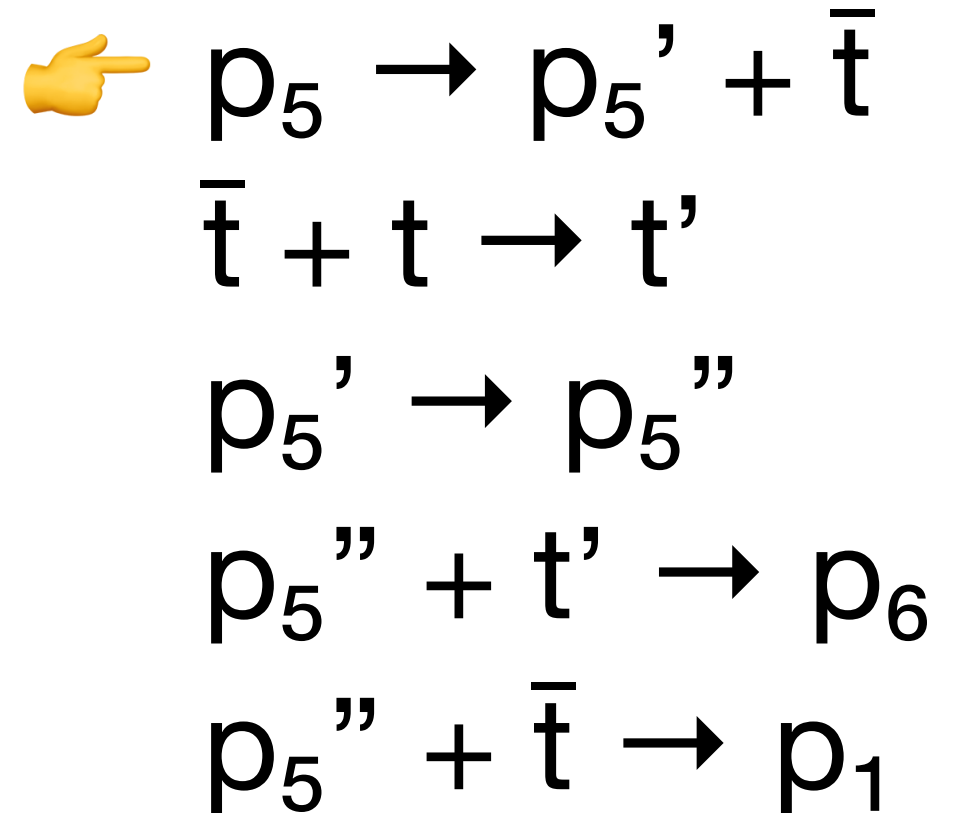
5: dec(t), 6, 1



s'il n'y a
pas de t

Instructions → réactions

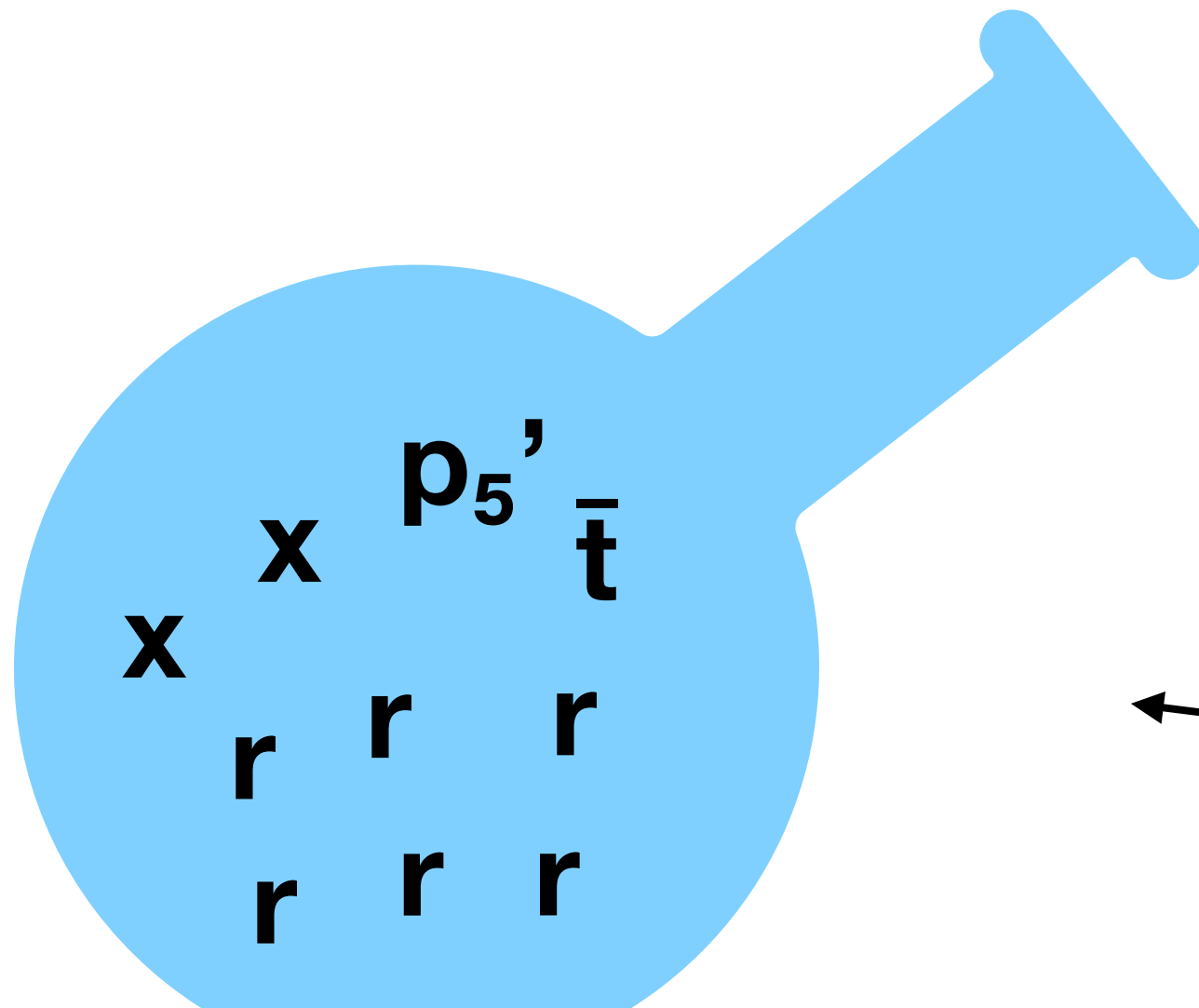
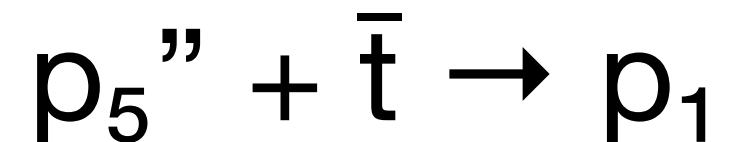
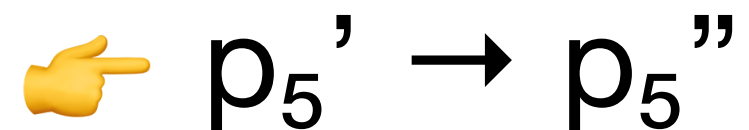
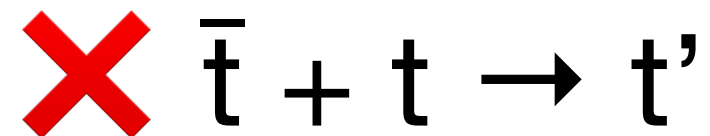
5: dec(t), 6, 1



← s'il n'y a pas de t

Instructions → réactions

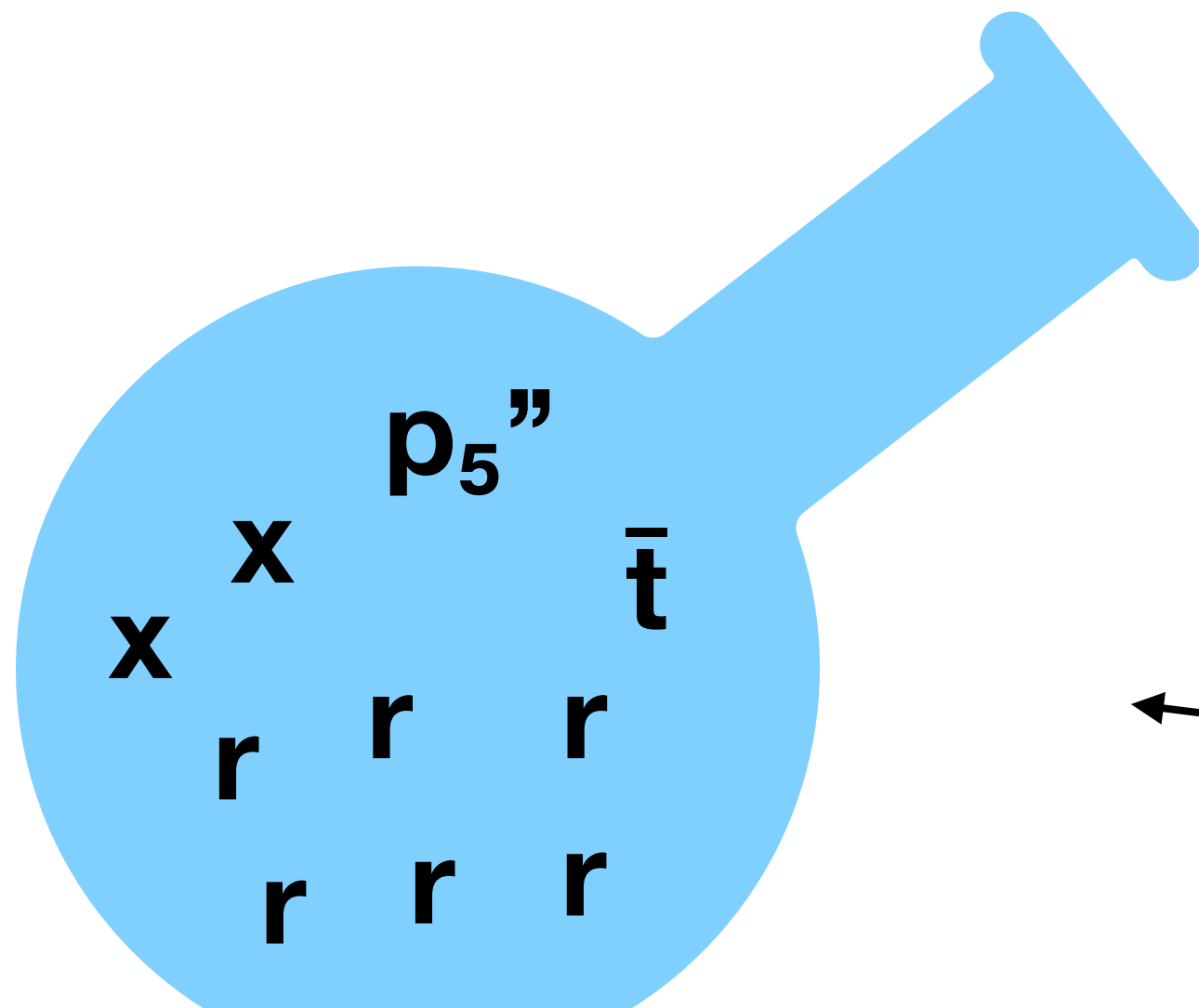
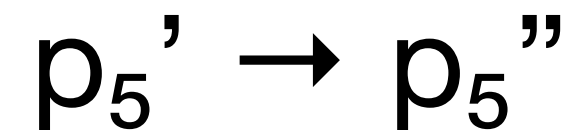
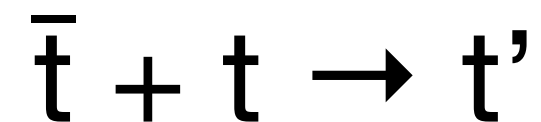
5: dec(t), 6, 1



← s'il n'y a pas de t

Instructions → réactions

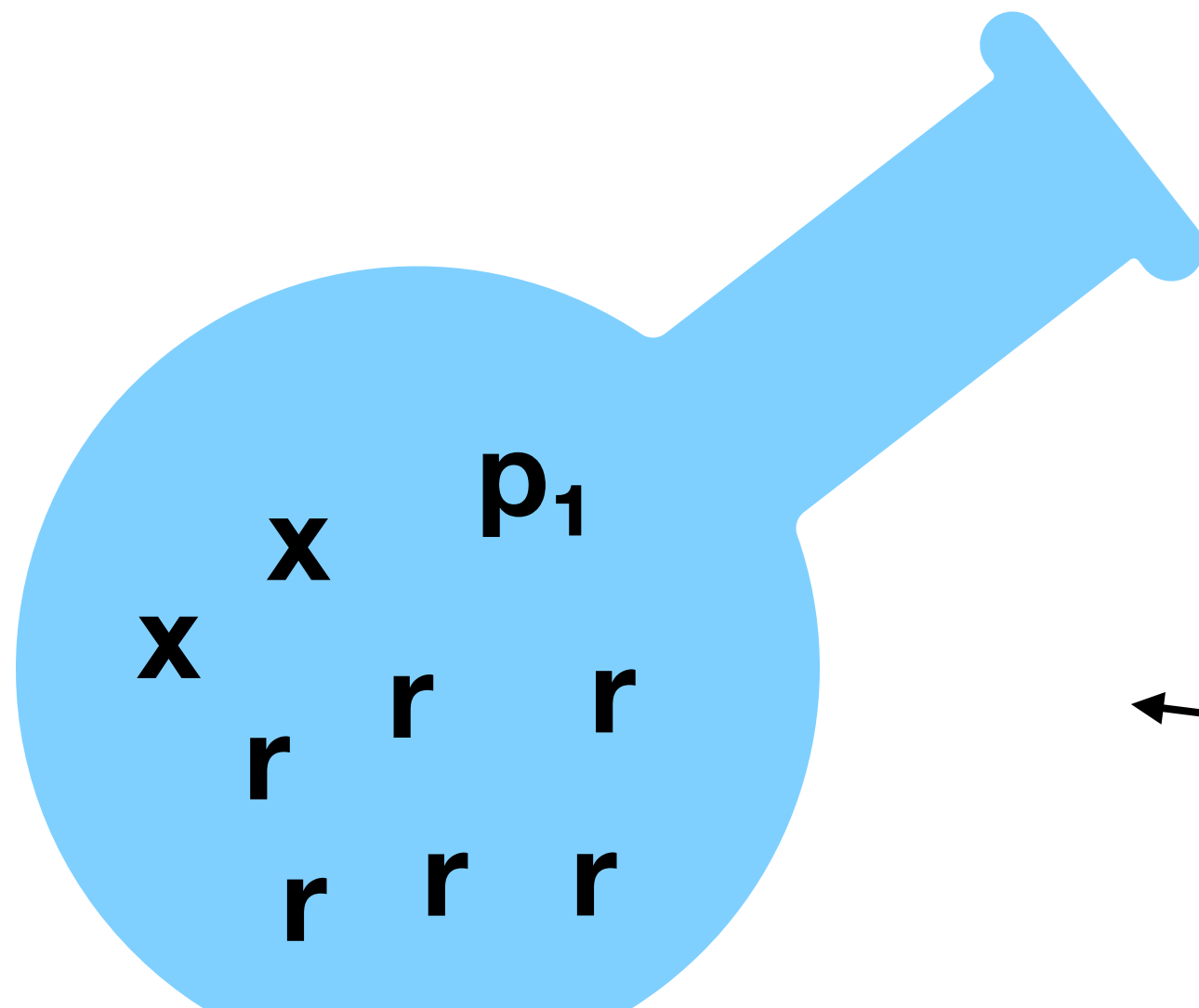
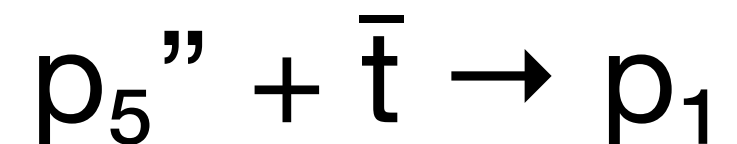
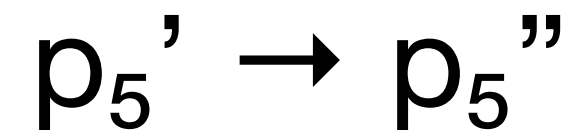
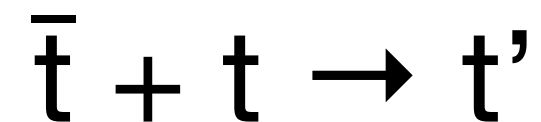
5: dec(t), 6, 1



← s'il n'y a pas de t

Instructions → réactions

5: dec(t), 6, 1



← s'il n'y a pas de t