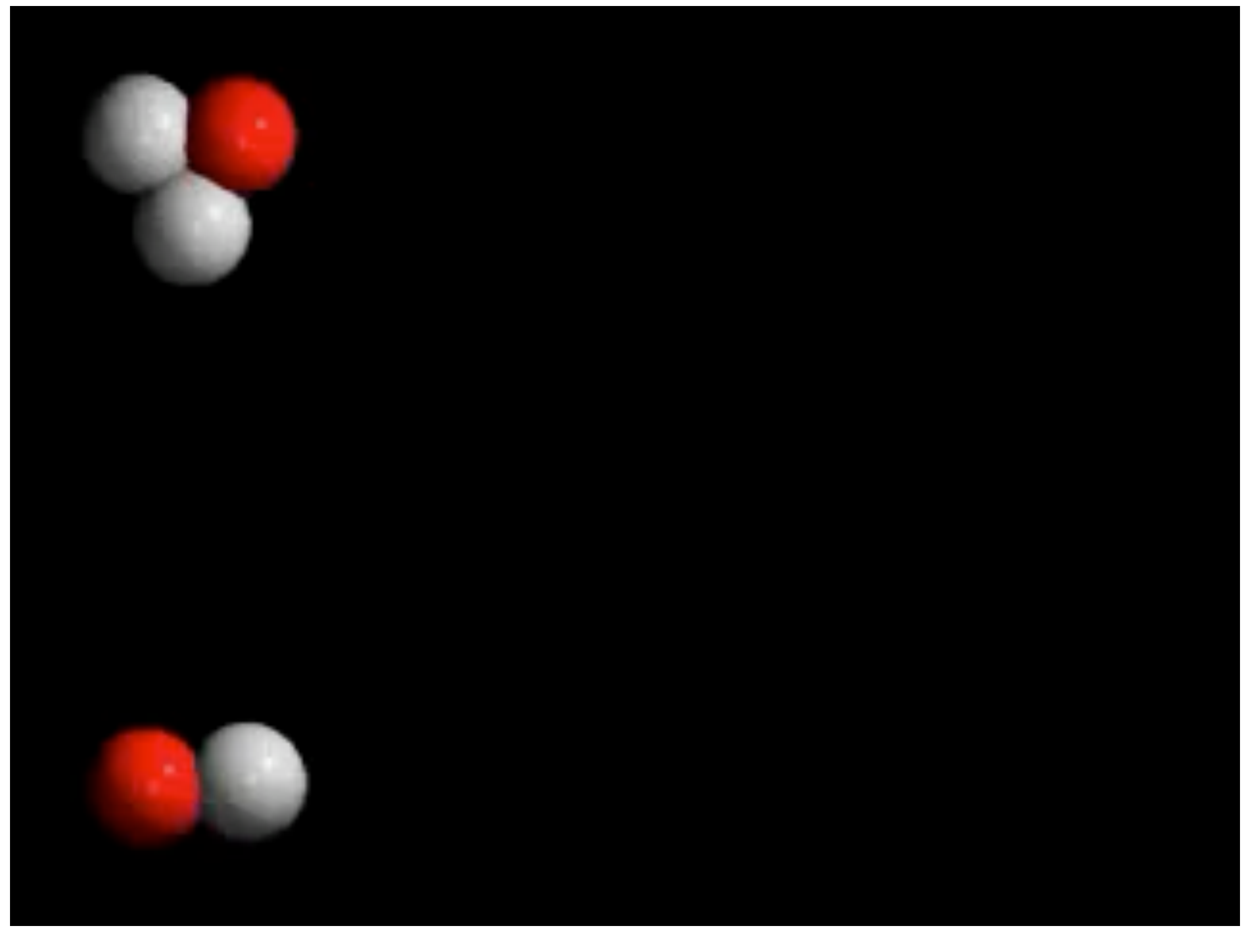
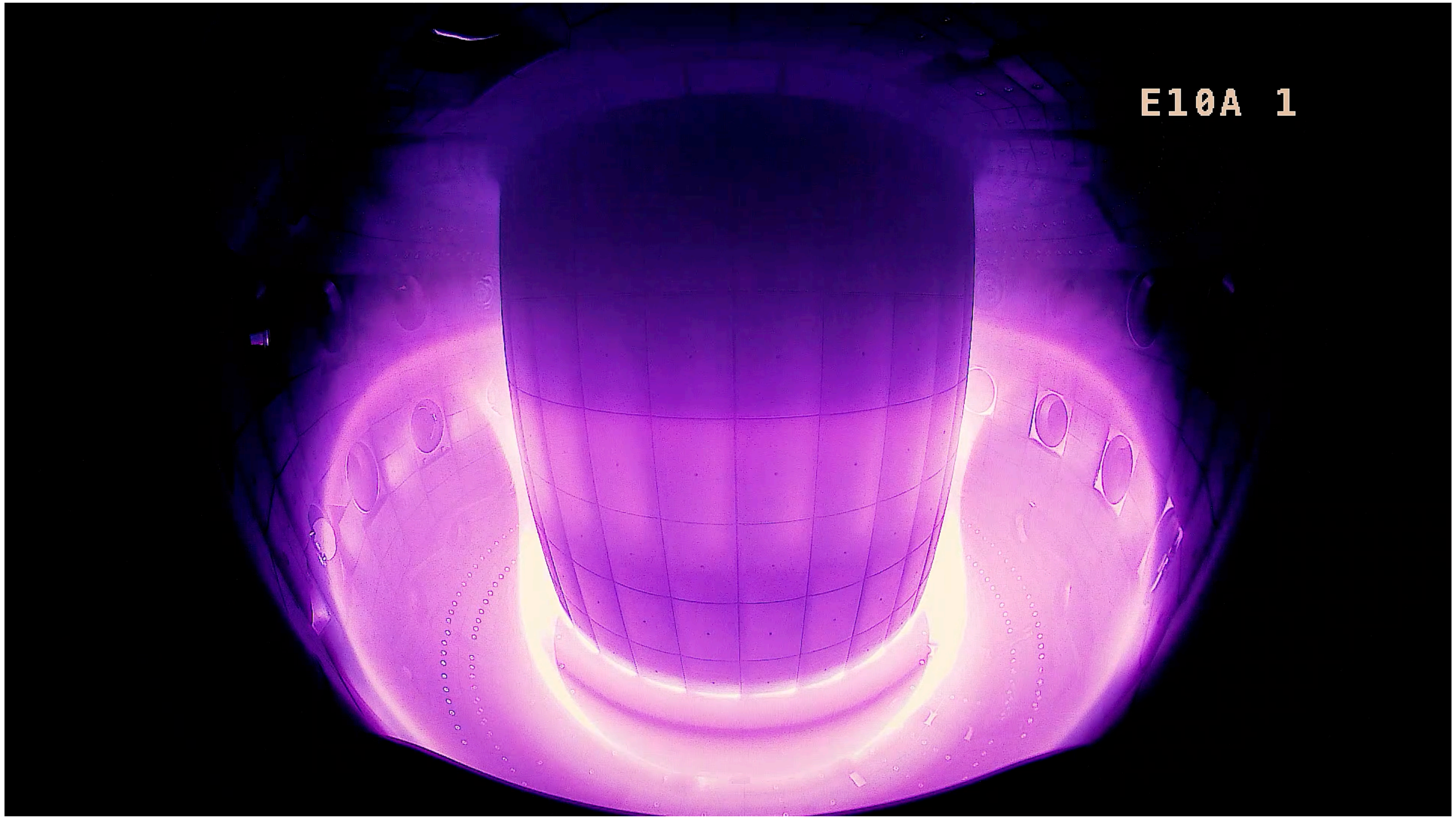
General Physics: Mechanics





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PHYS-101(en)

Lecture 10b: Collisions

Dr. Marcelo Baquero
marcelo.baquero@epfl.ch
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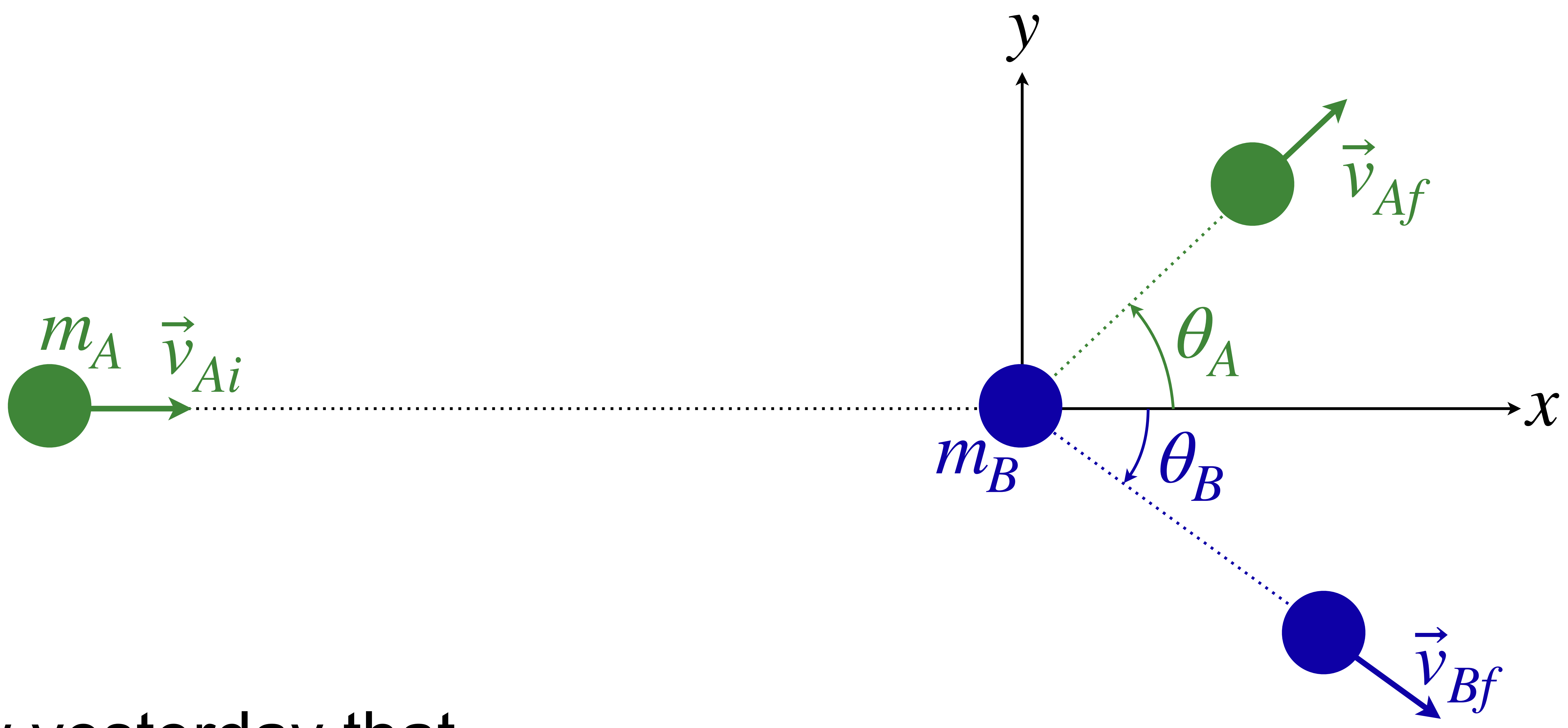
2D elastic collisions, **same** mass

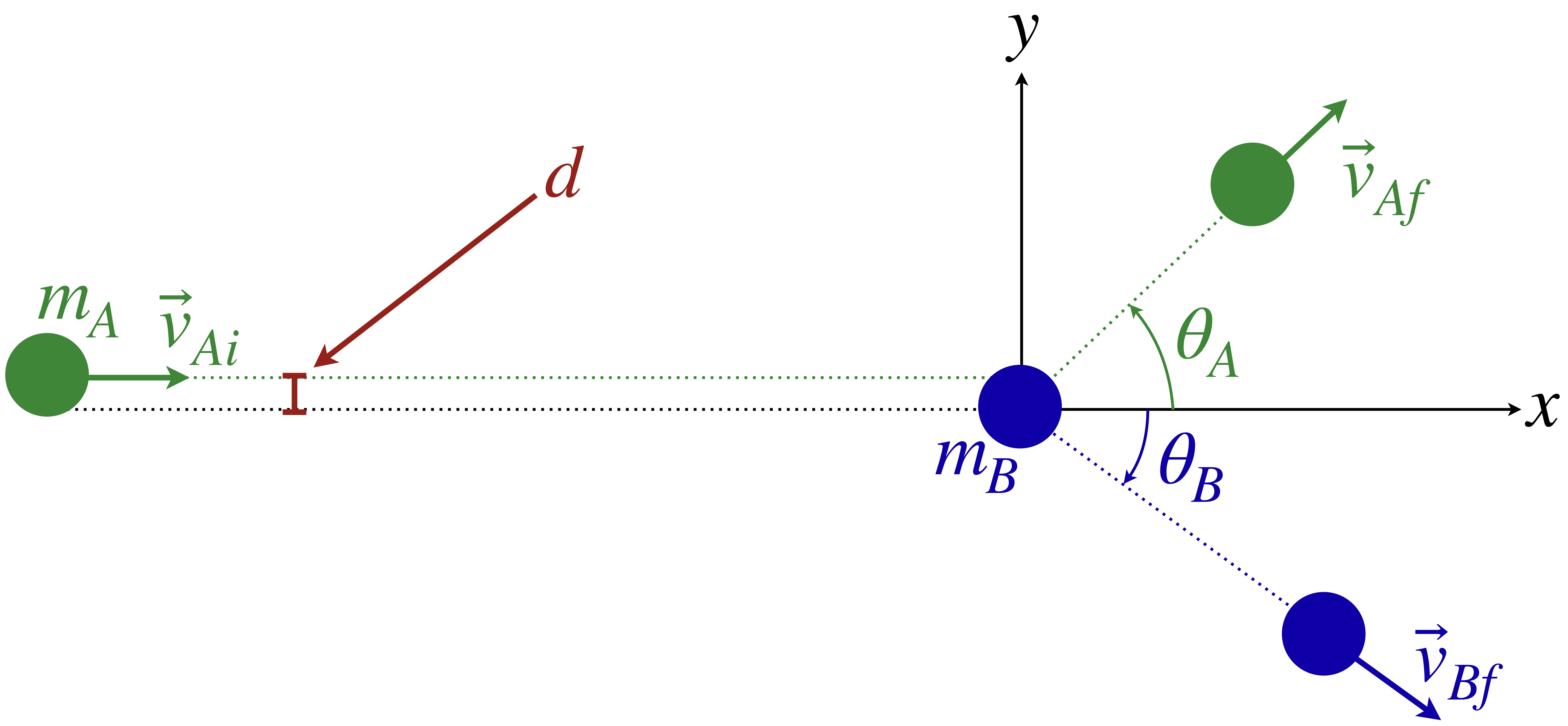


We saw yesterday that

$$0 = 2\, v_{Af}\, v_{Bf}\, \cos(\theta_A + \theta_B)$$

$$\begin{cases} v_{Af} = 0 & \text{Head-on collision} \\ v_{Bf} = 0 & \text{No collision} \\ \cos(\theta_A + \theta_B) = 0 \Rightarrow \theta_A + \theta_B = \pm \frac{\pi}{2} \end{cases}$$

2D elastic collisions, **same** mass



- To solve for the 4 unknowns (v_{Af}, v_{Bf}, θ_A, θ_B), we need a fourth equation
- Knowing the "impact parameter" d, allows you to directly determine θ_B

Conceptual question

1D problem

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$m_B = m_A \equiv m$

Cart A is at rest. An identical cart B is moving to the right and collides **elastically** with cart A. After the collision, which of the following is true

A. Carts A and B are both at rest.
B. Cart B stops and cart A moves to the right with speed equal to the original speed of cart B.
C. Cart A remains at rest and cart B bounces back with speed equal to its original speed.
D. Cart A moves to the right with a speed slightly less than the original speed of cart B and cart B moves to the right with a very small speed.

$v_{Ai} = 0$
$v_{Bi} \neq 0$
$\Rightarrow$
$v_{Af} = v_{Bi}$
$v_{Bf} = v_{Ai} = 0$

Swap velocities

Conceptual question

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$m_A = m_B = m$

Cart A is at rest. An identical cart B, moving to the right, collides **inelastically** with cart A. They stick together. After the collision, which of the following is true.

A. Carts A and B are both at rest.
B. Carts A and B move to the right with a speed less than cart B's original speed.
C. Carts A and B moves to the right with speed greater than Cart B's original speed.
D. Cart B stops and cart A moves to the right with speed equal to the original speed of cart B.

$\vec{v}_{Ai} = 0$

$\vec{v}_{Bi} \neq 0$

$\vec{v}_{Af} = \vec{v}_{Bf} = \vec{v}_f$

Cons. of momentum: $\sum \vec{p}_i = \sum \vec{p}_f$

$m_B \vec{v}_{Bi} = (m_A + m_B)\vec{v}_f$

$\Rightarrow \vec{v}_f = \frac{m_B}{m_A + m_B}\vec{v}_{Bi} = \frac{m}{2m}\vec{v}_{Bi} = \frac{1}{2}\vec{v}_{Bi}$

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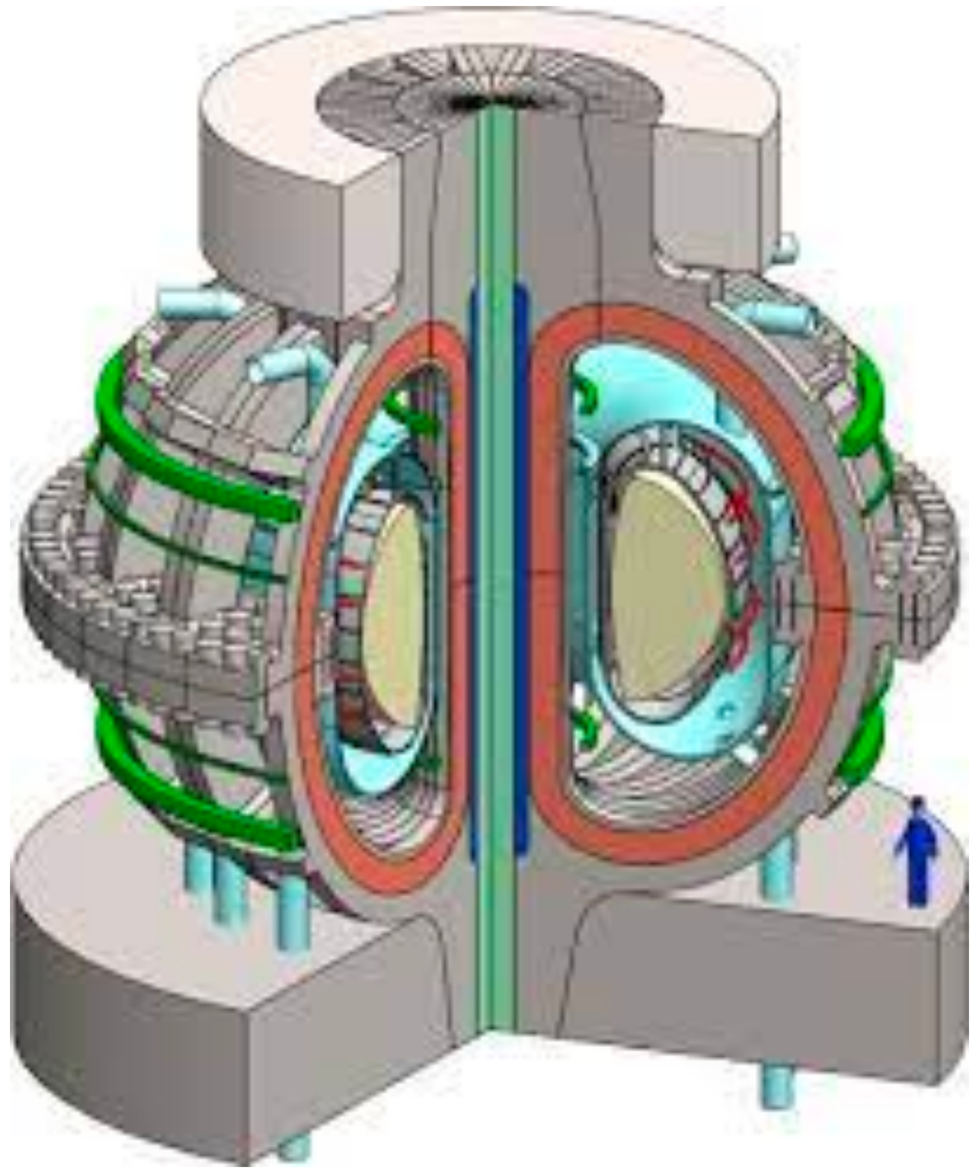
Example: Fusion reactions



In a fusion reactor, isotopes of hydrogen are confined as they are heated to temperatures exceeding those of the sun (i.e. 100 million Celsius = 0.01 MeV) in order to enable the fusion reaction

$$\overset{D}{{}^{2}H} + \overset{T}{{}^{3}H} \rightarrow \overset{\alpha}{{}^{4}He} + {}^{1}n \, .$$

AMU

$m_D = 2\,AMU$ $m_T = 3$ $m_\alpha = 4$ $m_n = 1$

This reaction is inelastic as it releases $Q = 17.6$ MeV of energy, which is carried away in the form of the kinetic energy of the products. If the ${}^{3}H$ particle is at rest and the ${}^{2}H$ particle has 0.01 MeV of kinetic energy, how much energy does the neutron end up with?

$\ll 17.6$ MeV

$\Rightarrow K_D \approx 0$

Hints:

- You can still write down a version of conservation of energy, but you need to consider all the types of energy involved
- Look for an approximation that simplifies the problem significantly and barely affects the final answer

Example: Fusion reactions

Energy: $\cancelto{\approx 0}{K_D} + \cancelto{0}{K_T} + \underbrace{U_{DT}}_{Q} = K_\alpha + K_n \Rightarrow Q \approx K_\alpha + K_n$ (1)

Cons. of momentum: $\cancelto{\approx 0}{\vec{p}_D} + \cancelto{0}{\vec{p}_T} = \vec{p}_\alpha + \vec{p}_n \Rightarrow \vec{p}_\alpha \approx -\vec{p}_n \Rightarrow m_\alpha \vec{v}_\alpha = -m_n \vec{v}_n \Rightarrow m_\alpha |\vec{v}_\alpha| = m_n |\vec{v}_n|$

Therefore $m_\alpha^2 v_\alpha^2 = m_n^2 v_n^2 \Rightarrow \frac{1}{2} m_\alpha v_\alpha^2 = \frac{m_n}{m_\alpha} \cdot \frac{1}{2} m_n v_n^2 \Rightarrow K_\alpha = \frac{m_n}{m_\alpha} K_n$ (2)

Now I replace (2) in (1):

$$Q = \frac{m_n}{m_\alpha} K_n + K_n = \left(\frac{m_n}{m_\alpha} + 1\right) K_n = \left(\frac{m_n + m_\alpha}{m_\alpha}\right) K_n \Rightarrow \boxed{K_n = \frac{m_\alpha}{m_\alpha + m_n} Q}$$

Replacing values, $K_n = \frac{4\,\text{AMU}}{(4+1)\,\text{AMU}} \cdot 17.6\,\text{MeV} = \frac{4}{5} \cdot 17.6\,\text{MeV} = 14.1\,\text{MeV}$

$$K_\alpha = \frac{1\,\text{AMU}}{4\,\text{AMU}} K_n = \frac{1}{4} \cdot 14.1\,\text{MeV} = 3.5\,\text{MeV}$$

Conceptual question

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An explosion splits an object initially at rest into two pieces of unequal mass. Which piece has the greater kinetic energy?

A. The less massive piece
B. The more massive piece
C. They both have the same kinetic energy
D. There is not enough information to tell

$$0 = m v_m + M v_M$$

$$\Rightarrow m v_m = -M v_M$$

$$\Rightarrow \frac{1}{2} m^2 v_m^2 = \frac{1}{2} M^2 v_M^2$$

$$\Rightarrow m K_m = M K_M$$

$$\Rightarrow K_m = \frac{M}{m} K_M$$

>1