

The background features a dark blue gradient with faint, glowing circular patterns and a scale. The scale is a semi-circular arc with tick marks and numerical labels: 150, 160, 170, 180, 190, 200, 220, 230, 240, 250, and 260. The circular patterns consist of concentric circles, some solid and some dashed, with arrows indicating clockwise or counter-clockwise rotation.

MOMENTUM CENTRIC PEDAGOGY OF NEWTON'S LAWS

TATSU TAKEUCHI, VIRGINIA TECH

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JOINT SPRING MEETING OF THE APPALACHIAN & CHESAPEAKE SECTIONS OF THE AAPT
CONCORD UNIVERSITY, ATHENS, WV

WHAT IS “FORCE?”

- Randall D. Knight,
Physics for Scientists and Engineers, a strategic approach, 3rd edition:
“A force is a push or a pull” (page 117)
- Nicholas J. Giordano, College Physics, Reasoning & Relationships, 2nd edition:
“A force is simply a push or a pull” (page 27)
- Debora M. Katz, Physics for Scientists and Engineers, Foundations and Connections with Modern Physics:
“A force is a push or a pull that is required to make an object accelerate” (page 123)
- Young and Freedman,
Sears & Zemansky’s University Physics with Modern Physics, 13th edition:
“A force is a push or a pull. A better definition is that a force is an interaction between two bodies or between a body and its environment” (page 105)
- Young & Stadler, Cutnell & Johnson Physics, 10th edition:
“A force is a push or a pull” (page 79)
- Eric Mazur, Principles and Practice of Physics:
“The force exerted on the object is the time rate of change in the object’s momentum” (page 177)

PROBLEMS WITH “A PUSH OR A PULL”

- Vague and not quantitative. Unscientific!
- Leads to many misconceptions and confusions:
 1. You can “feel” it when you are being **pushed** or **pulled**, so a “force” is something that you can “feel”
 - You “feel” weightless on the ISS so how can there be a force acting on you?
 2. Newton’s 3rd Law does not make any sense!
 - **Pushing** or **pulling** requires volition, so inanimate objects cannot supply a force
 - How can the wall **push** back when you **push** it?
 - How can action and reaction be of the same magnitude?
 - If the force with which the trailer is **pulling** the tractor is the same as the force with which the tractor is **pulling** the trailer, how can the two move at all?
- Does not explain why forces add like vectors

PROBLEMS WITH “A PUSH OR A PULL”

- Many textbooks try to overcome the various misconceptions by spending many pages or even chapters trying to guide, or indoctrinate the student into the correct understanding
- In the process, many authors inadvertently introduce many misconceptions of their own
- As a result, to the student, Newton’s Laws seem like a confusing mess of definitions, caveats, laws and rules that only apply on a case by case basis
- Don’t dig a hole (by defining “force” as “a push or a pull”) and then try to dig yourself out of it later!

BETTER DEFINITION OF “FORCE”

- Newton’s 2nd Law

$$\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

is not really a law but the definition of **force**
(After all, **force** is NOT an observable quantity)

- The **force** of A on B is the **rate of momentum transfer** from A to B
- **Force** is a vector since **momentum** is a vector,
and **momentum** is a vector since **velocity** is a vector,
and **velocity** is a vector since **displacement** is obviously a vector!
- Teach **momentum** first and **force** later!

NEWTON'S LAWS IN MOMENTUM-CENTRIC LANGUAGE

- Newton's 1st Law (aka Law of Inertia)

If an object does not exchange **momentum** with anything else, its **momentum** will remain unchanged

→ In Aristotle's "Physics," all objects come to rest because it is their "natural state," not because momentum is lost due to friction, i.e. in Aristotle's world view momentum is not conserved!

- Newton's 3rd Law (aka Action-Reaction Law)

When **momentum** is exchanged between objects A and B, the **momentum** lost by A is exactly the same as the **momentum** gained by B. No **momentum** is lost in the transaction.

NEWTON'S 3RD LAW IN DETAIL

- When **momentum** is exchanged between objects A and B, the **momentum** lost by A is exactly the same as the **momentum** gained by B. No **momentum** is lost in the transaction.
- Let's say that A "pushes" B and **momentum** $\Delta\vec{p}$ is transferred from A to B:

$$\Delta\vec{p}_A = -\Delta\vec{p}, \quad \Delta\vec{p}_B = \Delta\vec{p}$$

Note that A lost **momentum** $\Delta\vec{p}$ because it gave $\Delta\vec{p}$ to B by "pushing" it. NOT because B "reacted" to the push and "pushed back." It is a single transaction.

- The **rates of momentum transfer** are:

$$\vec{F}_{B \rightarrow A} = \frac{\Delta\vec{p}_A}{\Delta t} = -\frac{\Delta\vec{p}}{\Delta t} = -\frac{\Delta\vec{p}_B}{\Delta t} = -\vec{F}_{A \rightarrow B}$$

- The "**reaction force**" is NOT the "reaction" to the "**action force!**"

“ACTION” & “REACTION” ARE MISLEADING

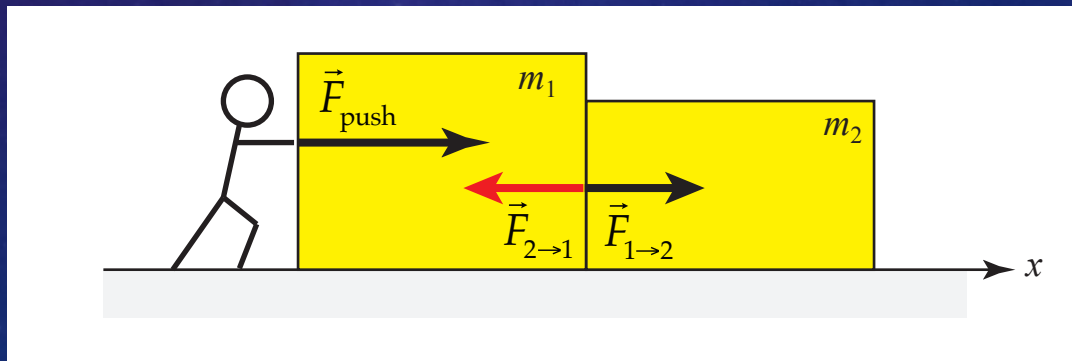
- Proposal: rename the “action-reaction law” as the “**credit-debit law**”

$$\Delta\vec{p}_A = -\Delta\vec{p}, \quad \Delta\vec{p}_B = \Delta\vec{p}$$

$\Delta\vec{p}$ appears as a **credit** on B's momentum account

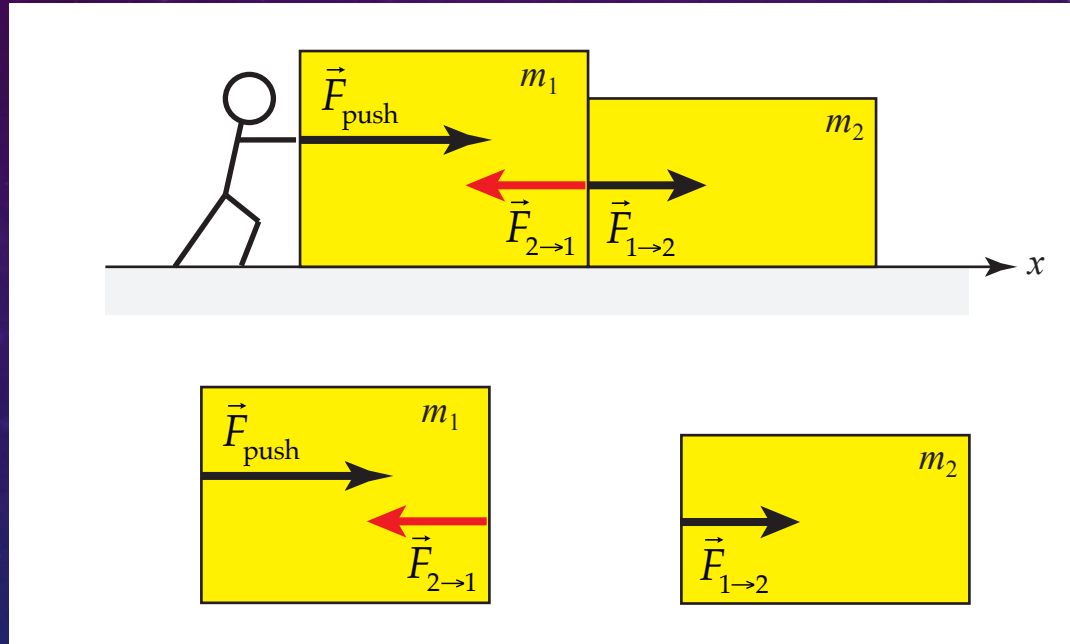
$\Delta\vec{p}$ appears as a **debit** on A's momentum account

- A's **debit** must be the same as B's **credit**
- Use black and red arrows to indicate **credit** and **debit** forces:



“FREE BODY DIAGRAM” IS ALSO A WEIRD TERM

- Proposal: rename the “free body diagram” the “**momentum accounting diagram**”



OTHER BENEFITS

- “**Impulse**” becomes a redundant concept since it is the same thing as “**momentum transfer**”
→ when it is necessary to emphasize that Δt is small, call it the “**instantaneous momentum transfer**”
- No need to invoke the **impulse-momentum law** to derive the **pressure** of an ideal gas from the kinetic theory of gases
- **Air drag/lift** obviously has to be proportional to the velocity squared since the **number of air molecules that you collide with per unit time**, and the **amount of momentum transferred to you from an air molecule per collision** are both proportional to the velocity
- **Internal forces** of an extended object are irrelevant to the motion of its center-of-mass since they represent **momentum transfer from one part of the object to another**.