Ne t c ... Physi ...

Q: ... qua ... "...ion", ... effort
required to Stop ... one hand

- baseb... with $v = 60$ mph
- linebacker with $v = 6$ mph
- train with $v = 0{\cdot}2$ mph ?

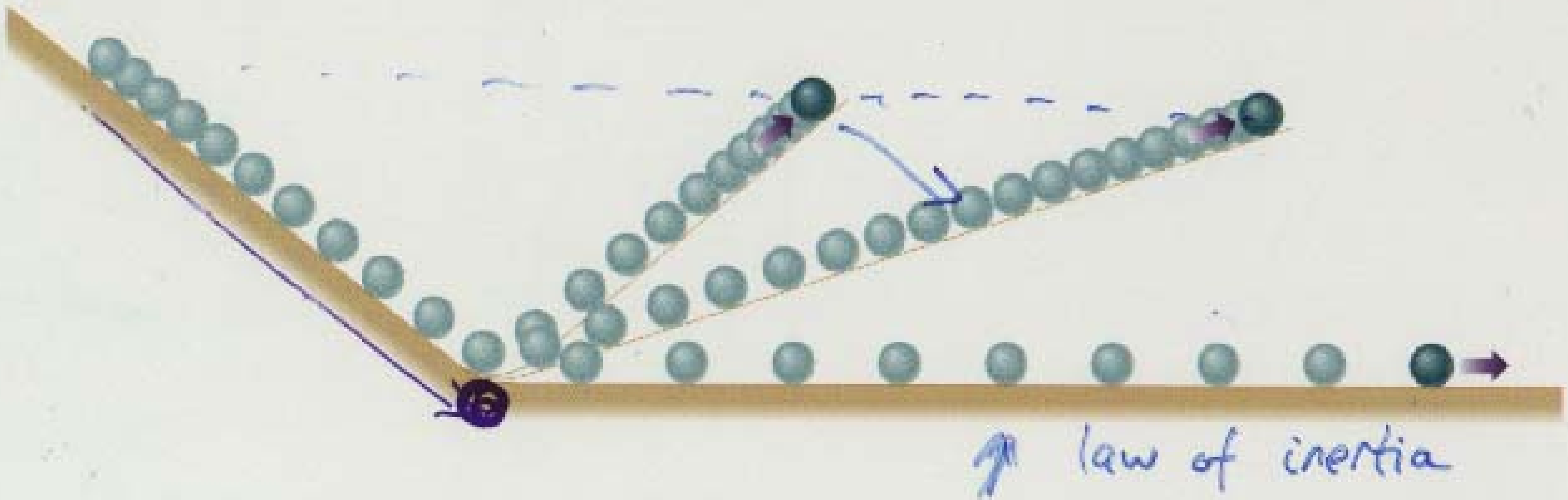
(Is there more to motion than just speed ?)

In "weightless" space :

- Can astronaut tell a full box of bolts from empty box?
  (Yes! Shake the box, but why?)
- If astronaut hits thumb with "weightless" hammer, does it hurt? (Yes - same as on earth!)
- On moon, or underwater, does weight belt add extra "gravity" without side-effects? (No!)
- If stranded in space, ~100m from Shuttle, how can astronaut return to safety?

  (Use hammer, box of bolt - anything that can be th...n)

Figure 4.1
Ball rolling down an incline plane illustrating the laws of inertia



Newton's 2nd Law: Force = rate of change of momentum

When object changes motion over time interval Δt, need to define "**force**" (effort) required to cause that change.

We want: Force $\propto$ mass

$\propto \Delta v$ in direction of $\Delta \vec{v}$

$\propto \frac{1}{\Delta t}$ ("gentle" vs. "harsh")

$\Rightarrow$ Force $\propto m\frac{\Delta v}{\Delta t} \propto \frac{\Delta p}{\Delta t}$ in direction of $\Delta\vec{v}, \Delta\vec{p}$.

Let $\Delta t \to 0 \Rightarrow$ Newton's 2nd Law:

"The rate of change of an object's momentum is proportional to the force applied in the direction of that change."

i.e. $$\boxed{\vec{F} = \frac{d\vec{p}}{dt}}$$ SI Units: $kg\,m s^{-2}$ or Newton

$\vec{F} = m\vec{a}$: Mass as "inertial resistance" to change of motion.

We have $\vec{F} = \dfrac{d\vec{p}}{dt} = m\dfrac{d\vec{v}}{dt} = m\vec{a}$

$\therefore$ For given applied force ("cause"), the effect is an acceleration $a = \dfrac{F}{m}$: note depends on mass not weight

e.g. On moon, objects weigh 1/6 of earth weight ($g_M \approx 1/6\, g$)

<u>BUT</u> massive objects are still difficult to accelerate/decelerate.

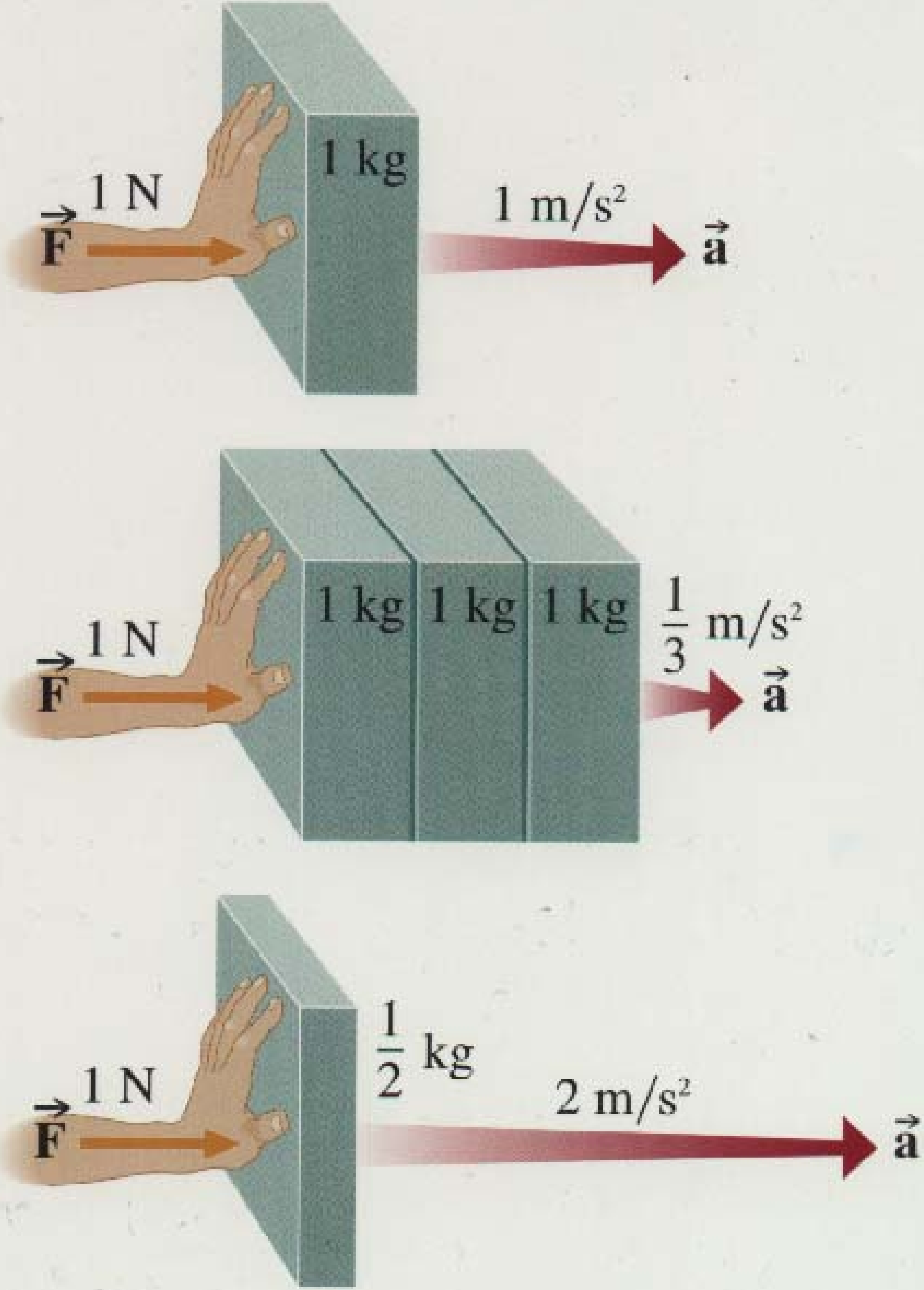
e.g. Weight belt increases force of gravity downwards, but also increases inertia

e.g. In "weightless" space, shake box of bolts to determine if full or empty (force required $\propto$ mass)

e.g. Change motion of "weightless" hammer with thumb.
Force $\propto$ mass $\times$ accel. $\Rightarrow$ ouch!

Figure 4.10

Examples of how $\vec{F}=m\vec{a}$ works

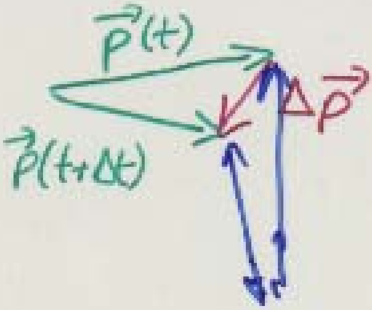


Momentum as Measure of Motion

Define: Momentum $\vec{p}$ = mass x velocity

$$\vec{p} = m\vec{v} \qquad (\text{kg m/s})$$

- $\vec{p}$ is a vector. Like $\vec{v}$, measured w.r.t. some inertial reference frame ("local standard of rest")
- <u>BUT</u> change in momentum $\Delta\vec{p} = m\Delta\vec{v}$ is not relative, i.e. all observers agree on the effect $\Delta\vec{p}$. (So they should agree on the cause: force)



c.f. height gain Δh here to Mt. Palomar
- regardless of sea level, center of earth, etc.

e.g. Baseball, $m = 0.2\,\text{kg}$, $v = 28\,\text{m/s}$

has $p = |\vec{p}| = 0.2 \times 28 = \underline{5.6\ \text{kg m/s}}$

linebacker $m = 100\,\text{kg}$, $v = 2.8\,\text{m/s}$

$p = 100 \times 2.8 = \underline{280\ \text{kg m/s}}$

train $m = 10^5\,\text{kg}$, $v = 0.09\,\text{m/s}$

$p = 10^5 \times 0.09 = \underline{9000\ \text{kg m/s}}$

... now we know which is easiest to stop (smallest $\Delta p = p - 0$).