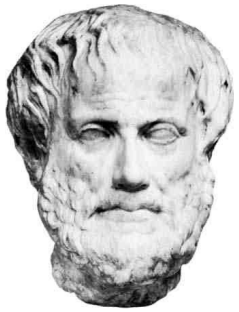
# 15. Galileo and Aristotle on Motion



## 1. Aristotle's Theory of Motion



- Two basic principles:

> I. *No motion without a mover in contact with moving body.*
> II. Distinction between:
> (a) *Natural motion*: mover is *internal* to moving body
> (b) *Forced motion*: mover is *external* to moving body

- *Forced motion*:
  - Non-natural (results in removal of object from its natural place).
  - Influenced by two factors: motive force $F$, and resistance of medium $R$.

- Aristotle's "Law of Motion": $V \propto F/R$, $V =$ speed.

> *Qualifications*:
> - Assumes $F > R$. When $F \leq R$, Aristotle says no motion occurs.
> - $V$ represents speed, not velocity.

*Question*: Which hits ground first: 1 lb ball or 10 lb ball?

- *Claim*: Aristotle's "law" predicts 1 lb ball will take 10 times longer to fall than 10 lb ball.

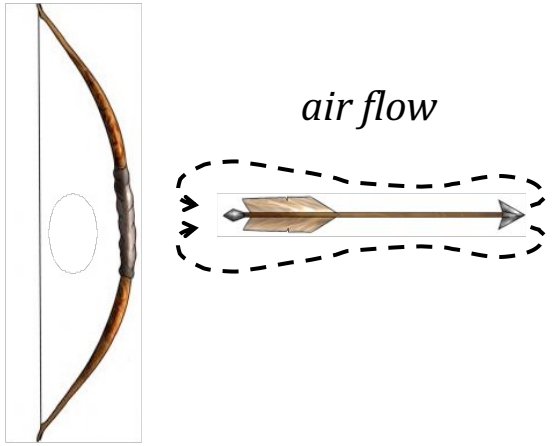
- Let $T$ = time required to travel a given distance.
- *Assume*: $V \propto 1/T$ (the greater the speed, the less the time of fall).
- Let $V_1$ = speed of 1 lb ball $T_1$ = time for 1 lb ball to hit ground
  $V_2$ = speed of 10 lb ball $T_2$ = time for 10 lb ball to hit ground.
- *Then*: $V_1/V_2 = T_2/T_1$.
- *Or*: $F_1/F_2 = T_2/T_1$ $(V \propto F)$.
- *So*: $1/10 = T_2/T_1$ or $T_1 = 10T_2$.

*Projectile Motion*

- *Big Problem*: What maintains the motion of a projectile after it's left the thrower's hand?

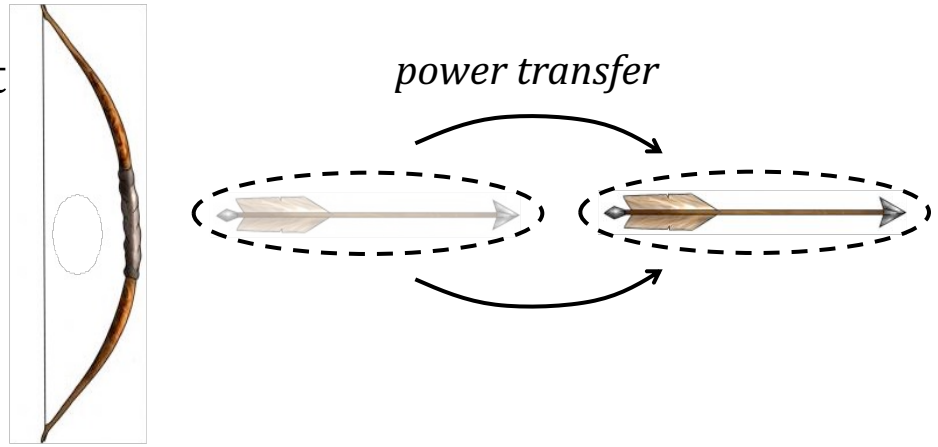
*Antiparistasis ("mutual replacement")*:

- Medium is the required contact force.
- Medium flows around object to fill in space left behind.
- *Result*: Object is pushed foward.




*Aristotle's Explanation*:

- Initial motive force transfers to the medium initially surrounding the object a "power" to act as a motive force.
- Medium then forces object into new region, which is then imparted with the "power" to act.



## *Later Aristotelian Developments*

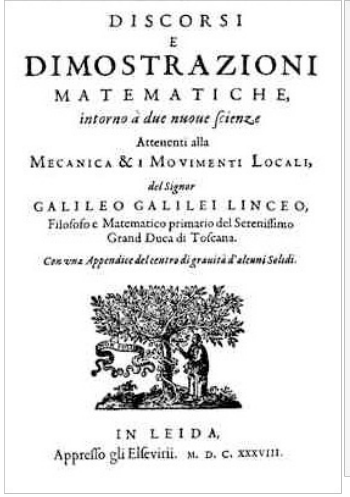
- John Philoponus (~490-570).
  - *Medium resists motion; it doesn't aid it.*
  - *Thus: "Power" to move is given not to medium but to object itself.*
  - *But: Motion in a vacuum is now possible.*
  - *And: How can this be reconciled with Aristotelian distinctions between natural and forced motion, and mover and moved.*

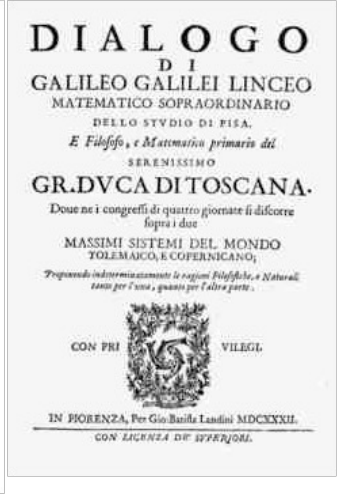
- Jean Buridan (~1300-~1360).
  - *"Impetus" is impressed force in projectile that is cause of continued motion.*
  - *The greater initial speed and amount of matter, the greater the impetus.*
  - *Not necessarily self-dissipating:*

"After leaving the arm of the thrower, the projectile would be moved by an impetus given to it by the thrower and would continue to be moved as long as the impetus remained stronger than the resistance, and would be of infinite duration were it not diminished and corrupted by a contrary force resisting it or by something inclining it to a contrary motion"

# 2. Galileo's Theory of Motion

- *Dialogue Concerning the Two Chief World Systems* (1632).
- *Dialogues Concerning Two New Sciences* (1638).


DISCORSI
E
DIMOSTRAZIONI
MATEMATICHE,
intorno à due nuoue scienze
Attenenti alla
MECANICA & i MOVIMENTI LOCALI,
del Signor
GALILEO GALILEI LINCEO,
Filosofo e Matematico primario del Serenissimo
Grand Duca di Toscana.
Con vna Appendice del centro di grauità d'alcuni Solidi.
IN LEIDA,
Appresso gli Elsevirii. M. D. C. XXXVIII.


DIALOGO
DI
GALILEO GALILEI LINCEO
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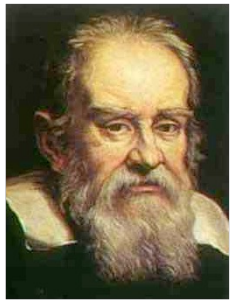
DELLO STVDIO DI PISA,
E Filosofo, e Matematico primario del
SERENISSIMO
GR. DVCA DI TOSCANA.
Doue ne i congressi di quattro giornate si discorre sopra i due
MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;
CON PRI VILEGI.
IN FIORENZA, Per Gio: Batista Landini MDCXXXII.
CON LICENZA DE' SUPERIORI.

- *Recall*: Mechanical tradition characterized by geometrical analysis of nature.



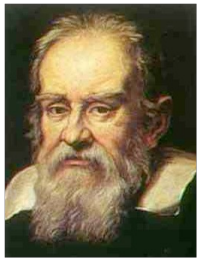
Galileo Galilei
(1564-1642)

"Nature is written in the language of mathematics and its characters are triangles, circles and other geometrical figures."

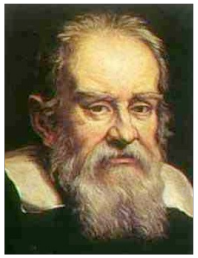
- Extents not only to descriptions of physical objects, but to *change* itself:

## (i) *Uniform Motion*

"By steady or uniform motion, I mean one in which the distances traversed by the moving particle during any equal intervals of time, are themselves equal."



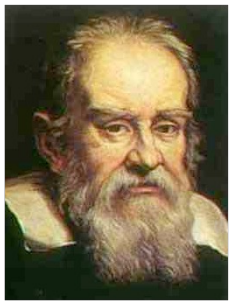
- Distance traversed is proportional to time of travel ($D \propto T$).
- *Claim*: Uniform motion is *undetectable* under certain conditions.



"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals... With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin... [Now] have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still... [T]he ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted."

- No way to tell (by experiments with butterflies, *etc*.) from within a closed frame of reference whether it is at rest or in uniform motion.
  - *Thus: Can't determine whether the Earth is at rest or in uniform motion.*

(ii) *Uniformly Accelerated Motion*

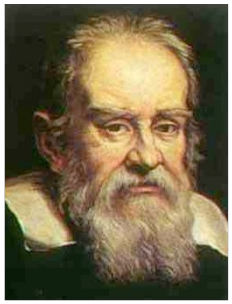


"A motion is said to be uniformly accelerated when starting from rest, it acquires, during equal time-intervals, equal increments of speed."

- Speed is proportional to time of travel ($V \propto T$).

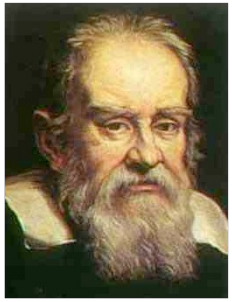
"*Mean Speed Rule*":

"The time in which any space is traversed by a body starting from rest and uniformly accelerated is equal to the time in which that same space would be traversed by a the same body moving at a uniform speed whose value is the mean of the highest speed and the speed just before acceleration began."



- In other words, $T = \dfrac{D}{\frac{1}{2}\left(V_{final} - V_{initial}\right)}$

"*Law of Free Falling Objects*":



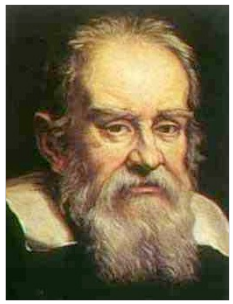
"The spaces described by a body falling from rest with a uniformly accelerated motion are to each other as the squares of the time-intervals employed in traversing these distances."

- In other words, $D \propto T^2$.

*Proof*:
- For uniformly accelerated body, $V = AT$ ($A$ = constant).
- *And*: $D = \frac{1}{2}(V_{final} - V_{initial})T$ (mean speed rule).
- *So*: $D = \frac{1}{2}AT^2$, or $D \propto T^2$ *for uniformly accererated body*.
- *And*: Free-fall motion can be approximated by uniformly accelerated motion on an inclined plane.

- *Implication*: $D/T \propto T$. The speed of a freely falling body only depends on the time of fall; not on the motive force (weight).
- *Thus*: A 1 lb ball and a 10 lb ball will hit the ground *at the same time* (all things being equal); as would a *feather and a hammer*.

# (iii) *Projectile Motion*



"A projectile which is carried by a uniform horizontal motion compounded with a naturally accelerated vertical motion describes a path which is a semi-parabola."

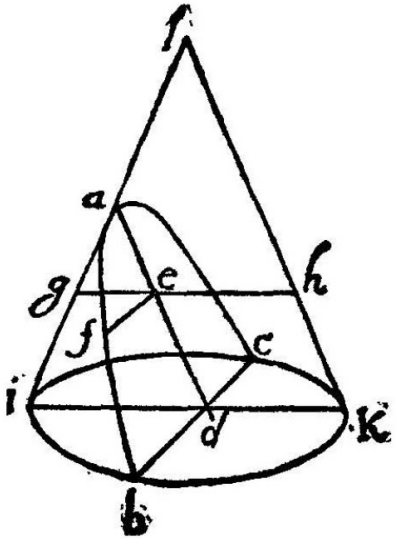
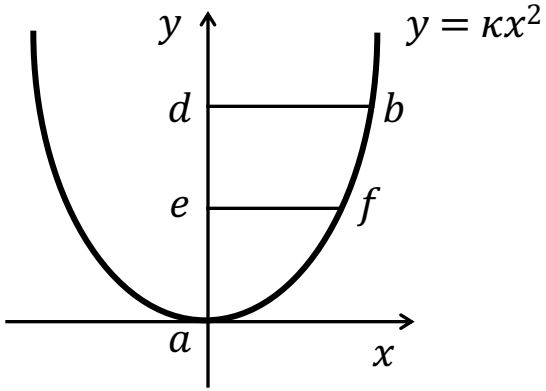


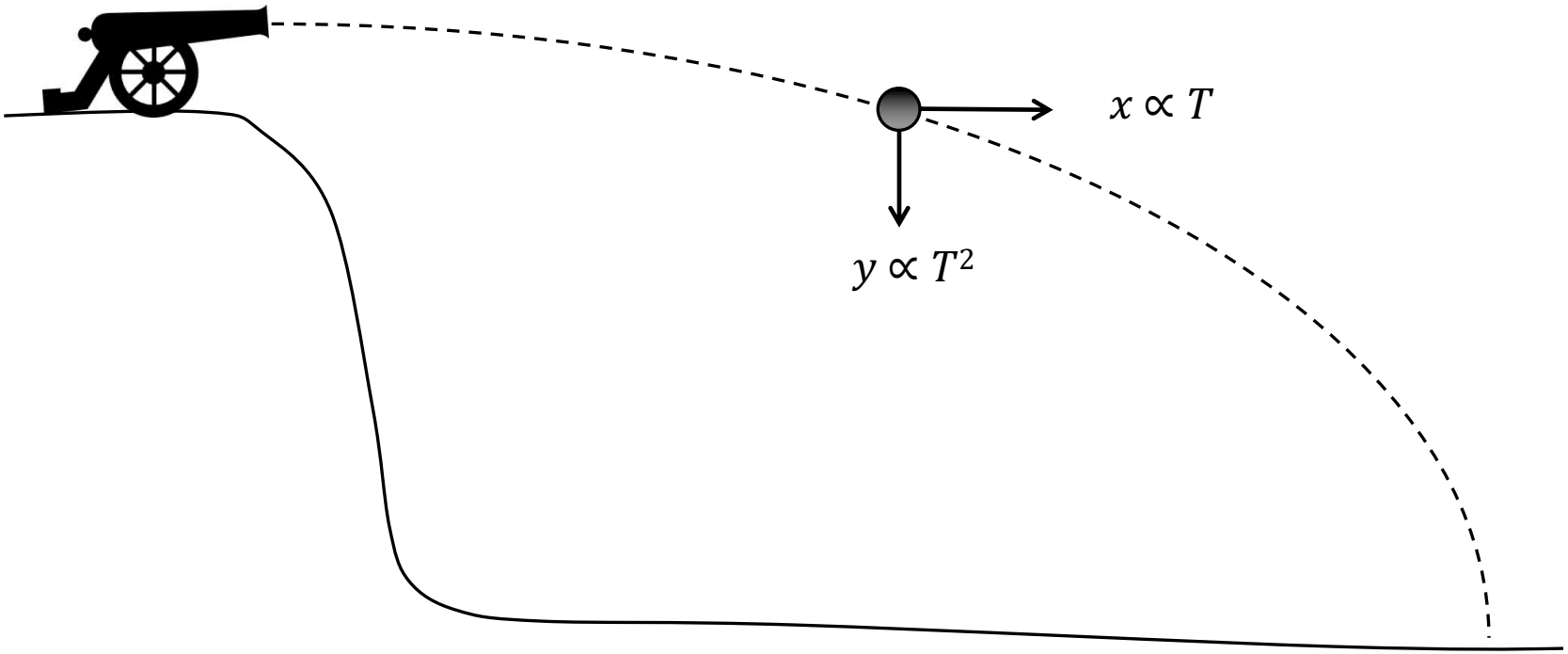
Fig. 106

- Parabola defined by: "The square of $bd$ is to the square of $fe$ in the same ratio as the axis $ad$ is to the portion $ae$."
- In other words, $(bd)^2/(fe)^2 = ad/ae$.
- Or, $y = \kappa x^2$



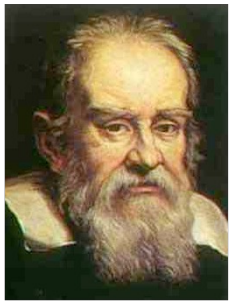
*Projectile motion* = (*uniform forward motion*) + (*free-fall motion*)

$D \propto T$ $\qquad\qquad$ $D \propto T^2$




- Path of cannonball is described by a horizontal component $x$ and a vertical component $y$ related to each other by $y \propto x^2$, or $y = \kappa x^2$, where $\kappa$ = constant.

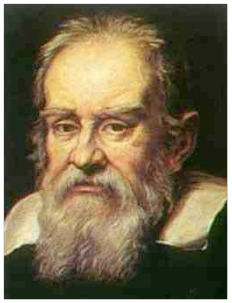
## (iv) *Further Statements Concerning Motion*

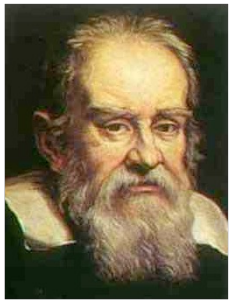


"...no matter how heavy the body, if it falls from a very considerable height, the resistance of the air will be such as to prevent any increase in speed and will render the motion uniform..."

- *Recall Aristotle*: When $R = F$, no motion can occur.
- *Implication*: Motion can continue in absence of external net forces.

"...[A]ny velocity once imparted to a moving body will be rigidly maintained as long as the external causes of acceleration or retardation are removed, a condition which is found only on horizontal planes...; from this it follows that motion along a horizontal plane is perpetual; for, if the velocity be uniform, it canot be diminished or slackened, much less destroyed."

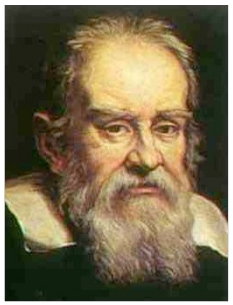




"I mentally conceive of some moveable projected on a horizontal plane, all impediments being put aside. Now it is evident from what has been said elsewhere at greater length that equable [i.e., uniform] motion on this plane would be perpetual if the plane were of infinite extent."

- A ball rolling on an infinite plane will continue to roll indefinitely unless a retarding force is applied.
- <u>*But*</u>: Infinite planes do not exist in nature.
  - *Motion only occurs along spherical sections of the earth's surface.*
- <u>*Thus*</u>: An object moving uniformly and unimpeded *on the earth's surface* will continue.

## (v) *Aristotelian Influences*



"Every body constituted in a state of rest but naturally capable of motion will move when set at lierty only if it has a natural tnedency toward some particular place... Besides, straight line motion being by nature infinite..., it is impossible that anything should have by nature the principle of moving in a straight line; or, in other words, toward a place where it is impossible to arrive, there being no finite end. For nature, as Aristotle well says himself, never undertakes to do that which cannot be done, nor endeavors to move whither it is impossible to arrive."

- Rectilinear motion is *locomotion*: motion from initial place to final place.
  - *Thus*: *No perpetual motion along a straight line (only motion along line segments).*

- Privileged status of circular motion (after Copernicus):
  - *Rejection of Kepler's eliptic orbits.*
  - *Only circular motion is infinite.*