2019 CMwBang! site

Class YouTube Channel

Lecture 6
Mon. 9.16.2019

Geometry of common power-law potentials

Geometric (Power) series

"Zig-Zag" exponential geometry

Projective or perspective geometry

Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields

Coulomb geometry of $-1/r$-potential and $-1/r^2$-force fields

Compare mks units of Coulomb Electrostatic vs. Gravity

Geometry of idealized "Sophomore-physics Earth"

Coulomb field outside *Isotropic Harmonic Oscillator (IHO) field inside*

Contact-geometry of potential curve(s)

"Crushed-Earth" models: 3 key energy "steps" and 4 key energy "levels"

Earth matter vs nuclear matter:

*Introducing the "neutron starlet" and "***Black-Hole-Earth***"*

Introducing 2D IHO orbits and phasor geometry

Phasor "clock" geometry

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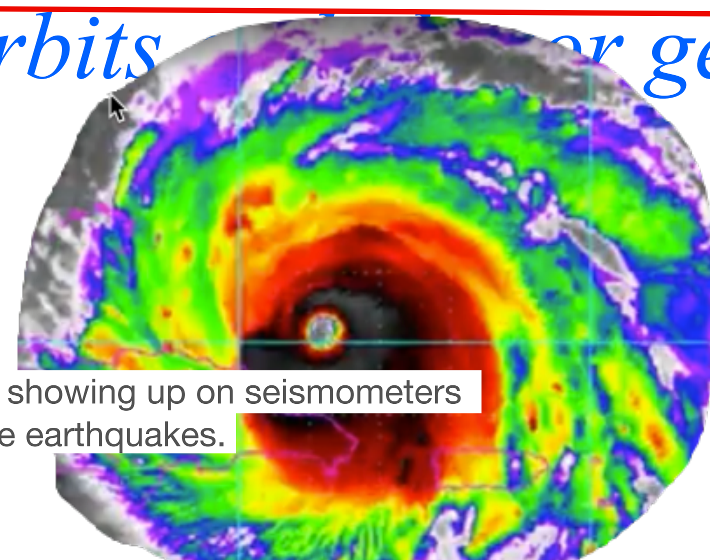
MONSTERS!

Introducing 2D IHO orbits … r geometry

Phasor "clock" geometry



Hurricane Dorian is so strong it's showing up on seismometers — equipment designed to measure earthquakes.

This year it's **Hurricane Dorian?**

This Lecture's Reference Link Listing

Web Resources - front page
UAF Physics UTube channel

Quantum Theory for the Computer Age
Principles of Symmetry, Dynamics, and Spectroscopy
Classical Mechanics with a Bang!
Modern Physics and its Classical Foundations

2017 Group Theory for QM
2018 Adv CM
2018 AMOP
2019 Advanced Mechanics

Lecture #6

RelaWavity Web Simulation: Contact Ellipsometry
BoxIt Web Simulation: Elliptical Motion (A-Type)
CMwBang Course: Site Title Page
Pirelli Relativity Challenge: Describing Wave Motion With Complex Phasors
UAF Physics UTube channel

These *are* hot off the presses. Out in MISC for quick reference.
Sorting_ultracold_atoms_in_a_three-dimensional_optical_lattice_in_a_realization_of_Maxwell's_Demon - Kumar-n-2018
Synthetic_three-dimensional_atomic_structures_assembled_atom_by_atom - Barredo-n-2018

Older ones:
Wave-particle_duality_of_C60_molecules - Arndt-ltn-1999
Optical_Vortex_Knots_-_One_Photon__At_A_Time - Tempone-Wiltshire-Sr-2018

References that did not make Lect 5, but that may have an affinity for the Independent Bounce Model covered there in:
Baryon_Deceleration_by_Strong_Chromofields_in_Ultrarelativistic_Nuclear_Collisions - Mishustin-PhysRevC-2007,
APS Link & Abstract
They treat collisions between ultrahigh energy nuclei as pair-wise independent collisions between "baryonic slabs"

Some Nuclei Hadronic material may behave or in times of extreme perturbation collapse or react as if it were comprised of clumps, of a size or composition more favorable, say: NP(Deuterium), He(Alpha), Carbon, …

Hadronic Molecules - Guo-x-2017
Hidden-charm_pentaquark_and_tetraquark_states - Chen-pr-2016

One might want to check spectra or design and observe collisions to look for evidence of compositional rotation and vibration structure, that more complex phenomena that we are just now acquiring the tools and techniques needed to describe and handle, and will be even better covered in our next Atomic, Molecular, Optical (AMO) or Group Theory (GT) offering.
A lot of cool tools for handling such composite Molecular behavior, and internalize as a natural continuation of the Geometric approach that we take here in this course.

Running Reference Link Listing

Prior to Lecture #6

Velocity Amplification in Collision Experiments Involving Superballs - Harter, 1971
MIT OpenCourseWare: High School/Physics/Impulse and Momentum
Hubble Site: Supernova - SN 1987A

BounceIt Web Animation - Scenarios:
Generic Scenario: 2-Balls dropped no Gravity (7:1) - V vs V Plot (Power=4)
1-Ball dropped w/Gravity=0.5 w/Potential Plot: Power=1, Power=4
7:1 - V vs V Plot: Power=1
3-Ball Stack (10:3:1) w/Newton plot (y vs t) - Power=4
3-Ball Stack (10:3:1) w/Newton plot (y vs t) - Power=1
3-Ball Stack (10:3:1) w/Newton plot (y vs t) - Power=1 w/Gaps
4-Ball Stack (27:9:3:1) w/Newton plot (y vs t) - Power=4
4-Newton's Balls (1:1:1:1) w/Newtonian plot (y vs t) - Power=4 w/Gaps
6-Ball Totally Inelastic (1:1:1:1:1:1) w/Gaps: Newtonian plot (t vs x), V6 vs V5 plot
5-Ball Totally Inelastic Pile-up w/ 5-Stationary-Balls - Minkowski plot (t vs x1) w/Gaps
1-Ball Totally Inelastic Pile-up w/ 5-Stationary-Balls - Vx2 vs Vx1 plot w/Gaps

BounceItIt Web Animation - Scenarios:
49:1 y vs t, 49:1 V2 vs V1, 1:500:1 - 1D Gas Model w/ faux restorative force (Cool),
1:500:1 - 1D Gas (Warm), 1:500:1 - 1D Gas Model (Cool, Zoomed in),
Farey Sequence - Wolfram
Fractions - Ford-AMM-1938
Monstermash BounceItIt Animations:
1000:1 - V2 vs V1, 1000:1 with t vs x - Minkowski Plot
Quantum Revivals of Morse Oscillators and Farey-Ford Geometry - Li-Harter-2013
Quantum_Revivals_of_Morse_Oscillators_and_Farey-Ford_Geometry - Li-Harter-cpl-2015
Quant. Revivals of Morse Oscillators and Farey-Ford Geom. - Harter-Li-CPL-2015 (Publ.)
Velocity_Amplification_in_Collision_Experiments_Involving_Superballs-Harter-1971
WaveIt Web Animation - Scenarios:
Quantum_Carpet, Quantum_Carpet_wMBars,
Quantum_Carpet_BCar, Quantum_Carpet_BCar_wMBars
Wave Node Dynamics and Revival Symmetry in Quantum Rotors - Harter-JMS-2001
Wave Node Dynamics and Revival Symmetry in Quantum Rotors - Harter-jms-2001 (Publ.)

BounceIt Dual plots
m_1:m_2 = 3:1
v_2 vs v_1 and V_2 vs V_1, $(v_1, v_2)=(1, 0.1)$, $(v_1, v_2)=(1, 0)$
y_2 vs y_1 plots: $(v_1, v_2)=(1, 0.1)$, $(v_1, v_2)=(1, 0)$, $(v_1, v_2)=(1, -1)$
Estrangian plot *V_2 vs V_1: $(v_1, v_2)=(0, 1)$, $(v_1, v_2)=(1, -1)$*
m_1:m_2 = 4:1
v2 vs v1, y2 vs y1
m_1:m_2 = 100:1, *$(v_1, v_2)=(1, 0)$: V2 vs V1 Estrangian plot, y2 vs y1 plot*
With g=0 and 70:10 mass ratio
With non zero g, velocity dependent damping and mass ratio of 70:35
M_1=49, M_2=1 with Newtonian time plot
M_1=49, M_2=1 with V_2 vs V_1 plot
Example with friction
Low force constant with drag displaying a Pass-thru, Fall-Thru, Bounce-Off
m1:m2= 3:1 and (v1, v2) = (1, 0) Comparison with Estrangian

AJP article on superball dynamics
AAPT Summer Reading List
Scitation.org - AIP publications
HarterSoft Youtube Channel

X2 paper: *Velocity Amplification in Collision Experiments Involving Superballs - Harter, et. al. 1971 (pdf)*
Car Collision Web Simulator: https://modphys.hosted.uark.edu/markup/CMMotionWeb.html
Superball Collision Web Simulator: https://modphys.hosted.uark.edu/markup/BounceItWeb.html; with Scenarios: 1007
BounceIt web simulation with g=0 and 70:10 mass ratio
With non zero g, velocity dependent damping and mass ratio of 70:35
Elastic Collision Dual Panel Space vs Space: Space vs Time (Newton) , Time vs. Space(Minkowski)
Inelastic Collision Dual Panel Space vs Space: Space vs Time (Newton), Time vs. Space(Minkowski)
Matrix Collision Simulator: M_1=49, M_2=1 V_2 vs V_1 plot <<Under Construction>>

More *Advanced QM and classical references at the end of this Lecture*

Geometry of common power-law potentials

Geometric (Power) series

→ *"Zig-Zag" exponential geometry*

Projective or perspective geometry

Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields

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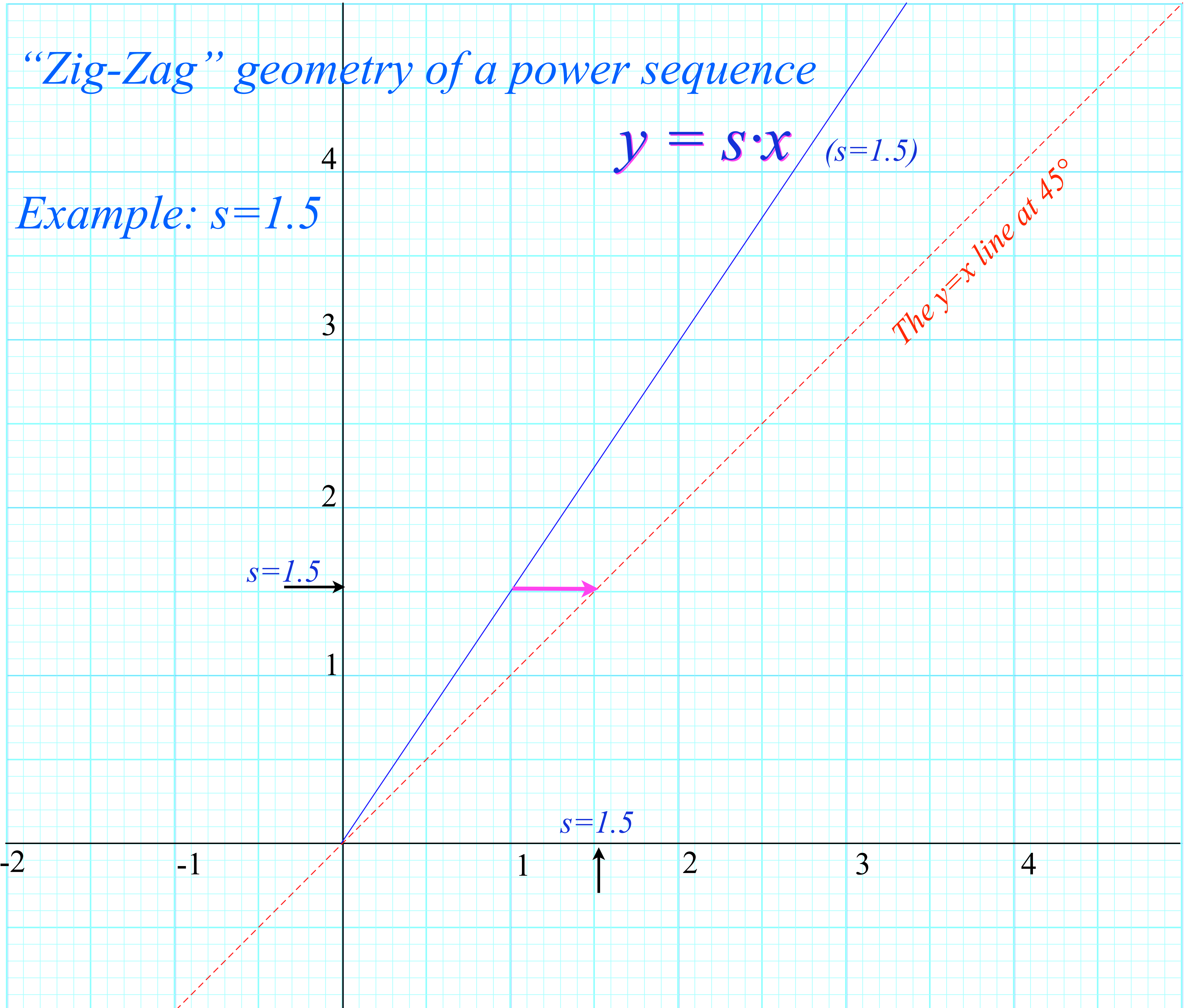
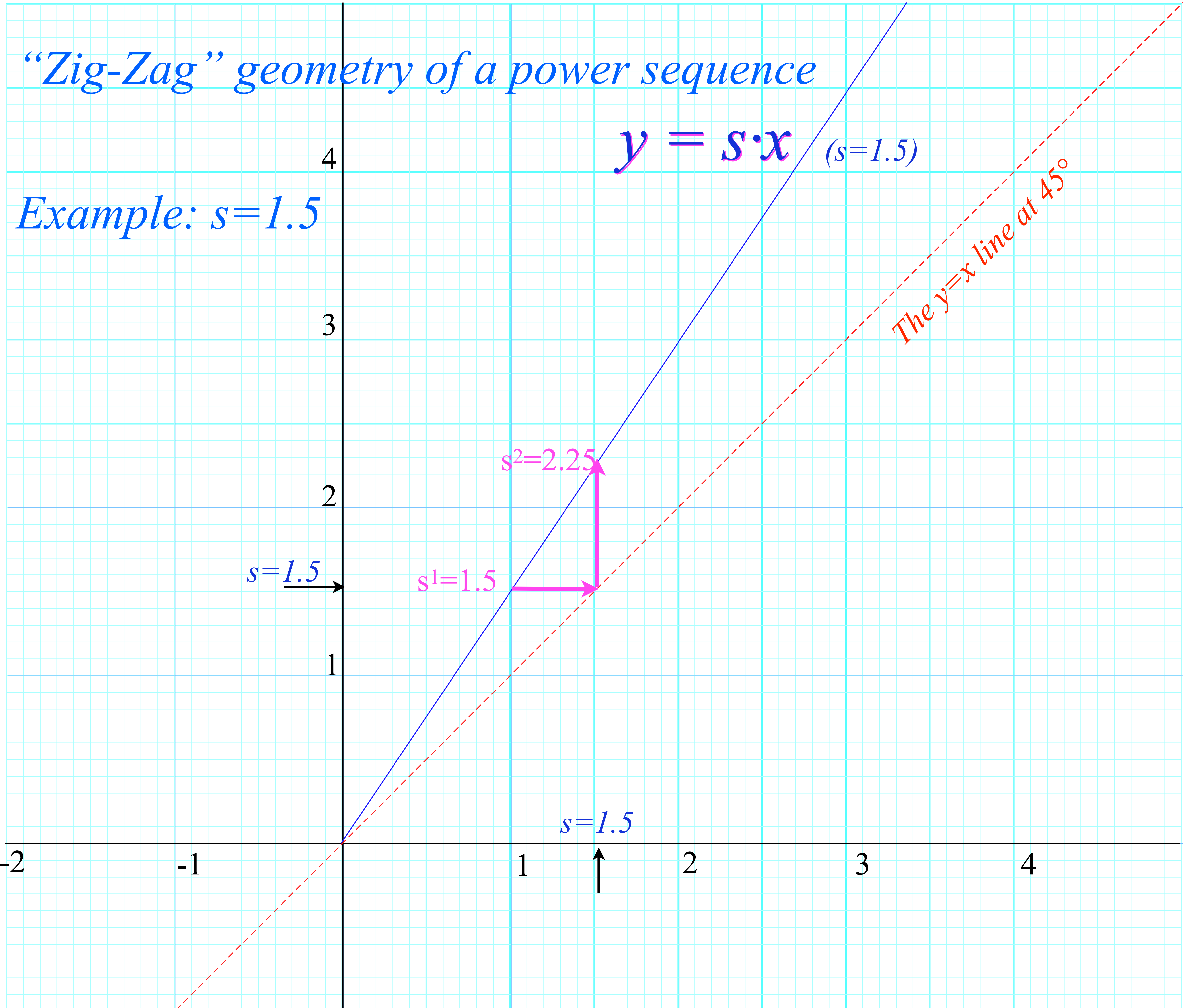
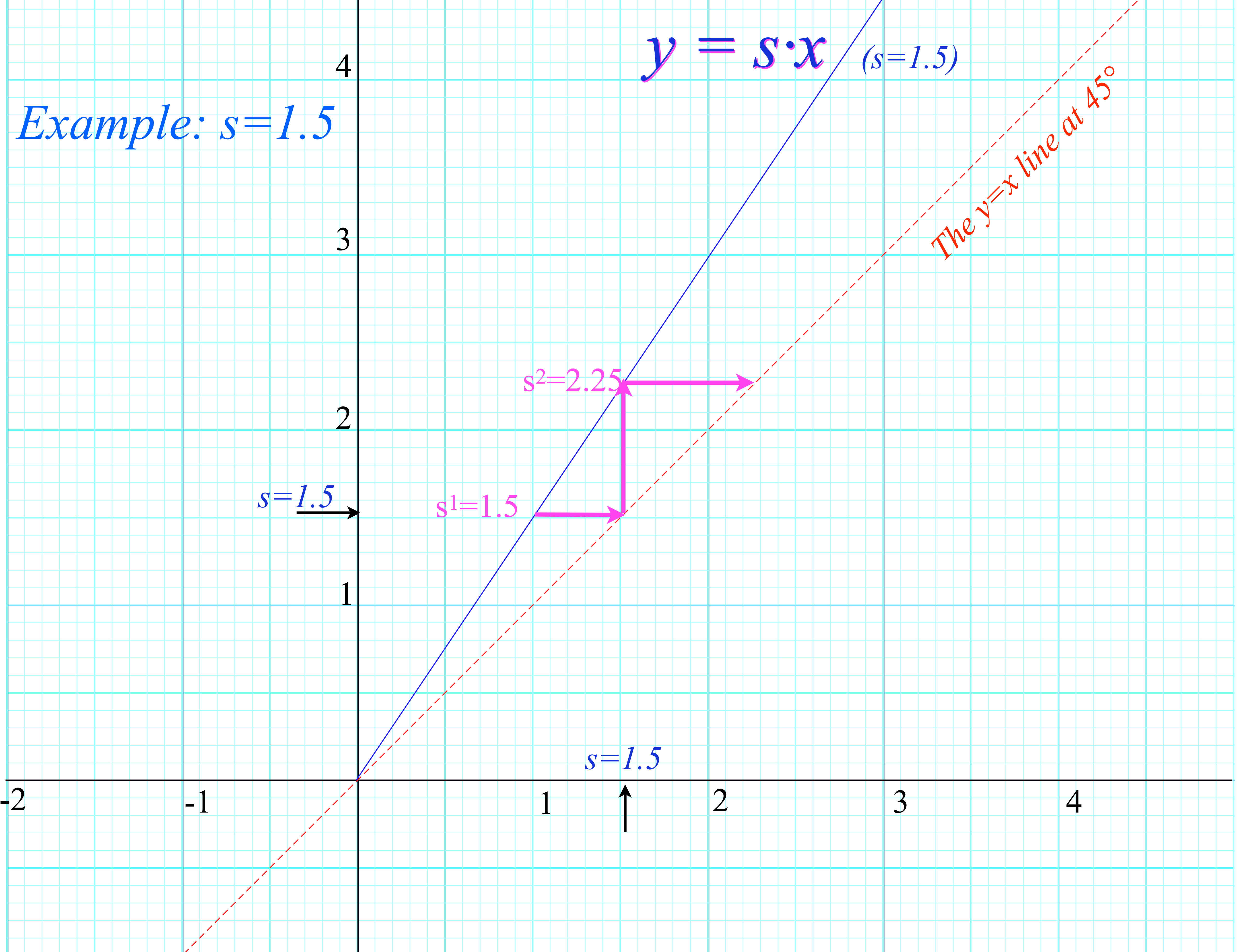
Compare mks units of Coulomb Electrostatic vs. Gravity

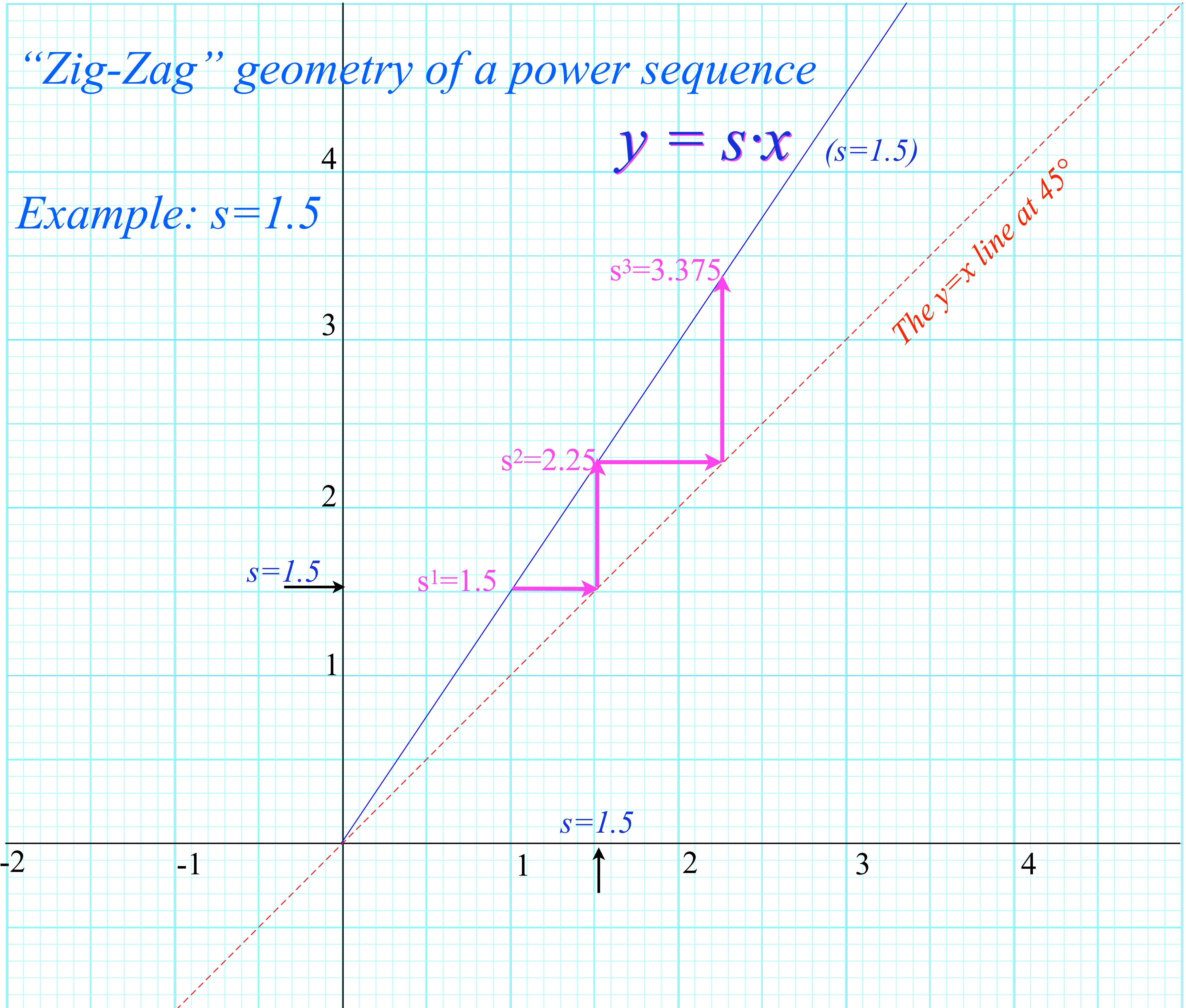


“Zig-Zag” geometry of a power sequence
y = s·x
(s=1.5)
Example: s=1.5
The y=x line at 45°
s=1.5
s=1.5
4
3
2
1
-2
-1
1
2
3
4

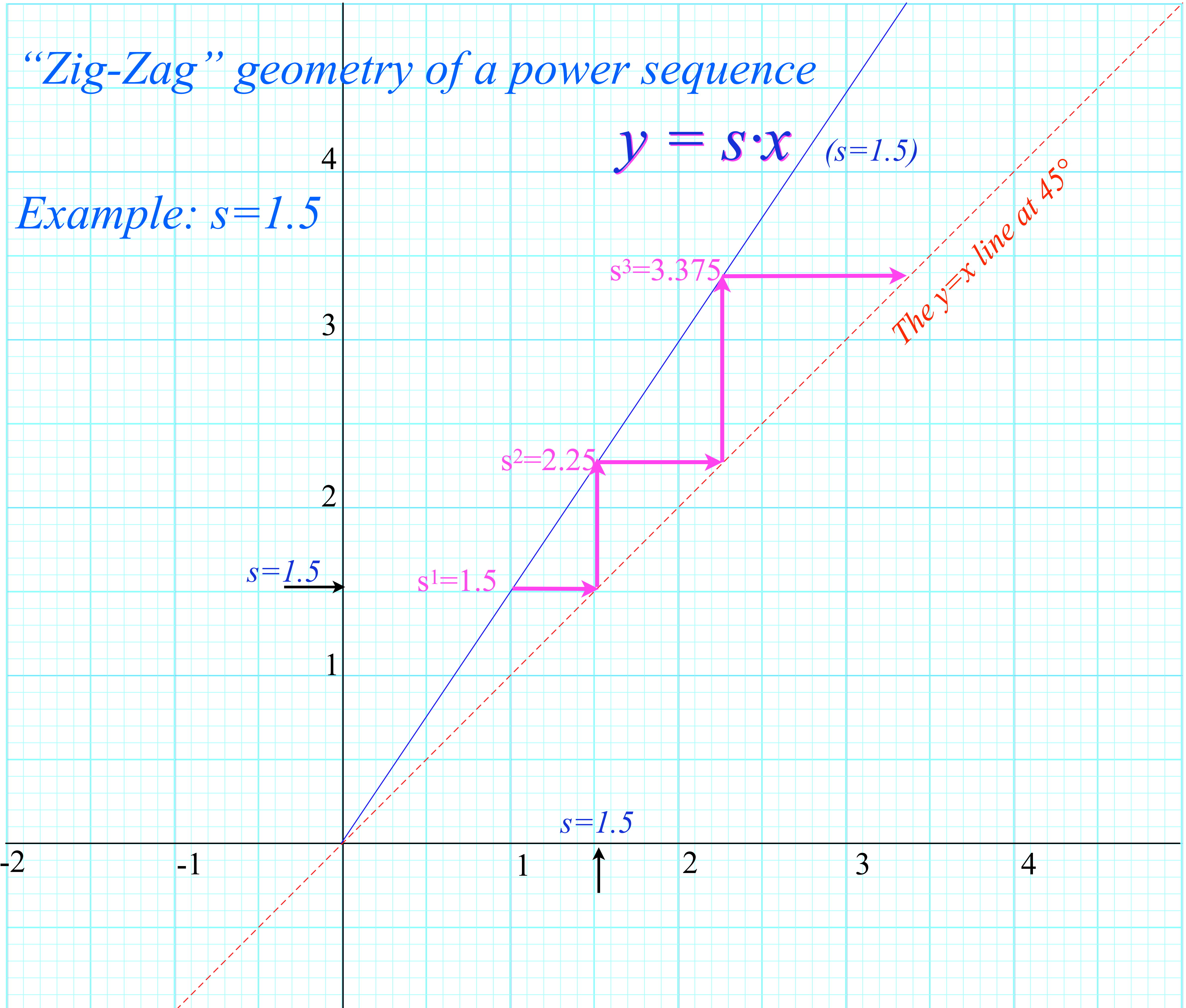

"Zig-Zag" geometry of a power sequence
Example: s=1.5
y = s·x
(s=1.5)
The y=x line at 45°
4
3
2
1
s=1.5
s¹=1.5
s²=2.25
s=1.5
-2
-1
1
2
3
4

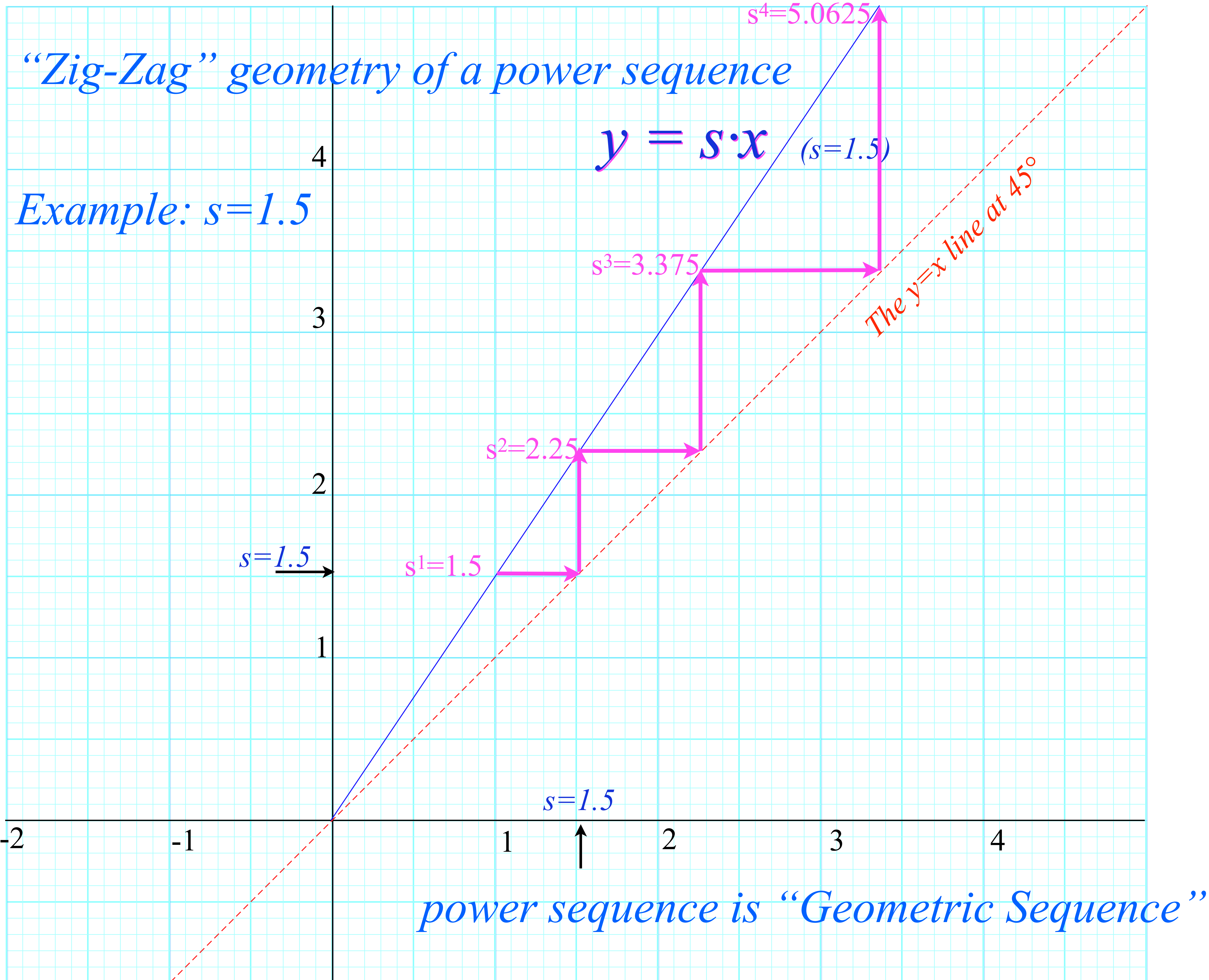
"Zig-Zag" geometry of a power sequence

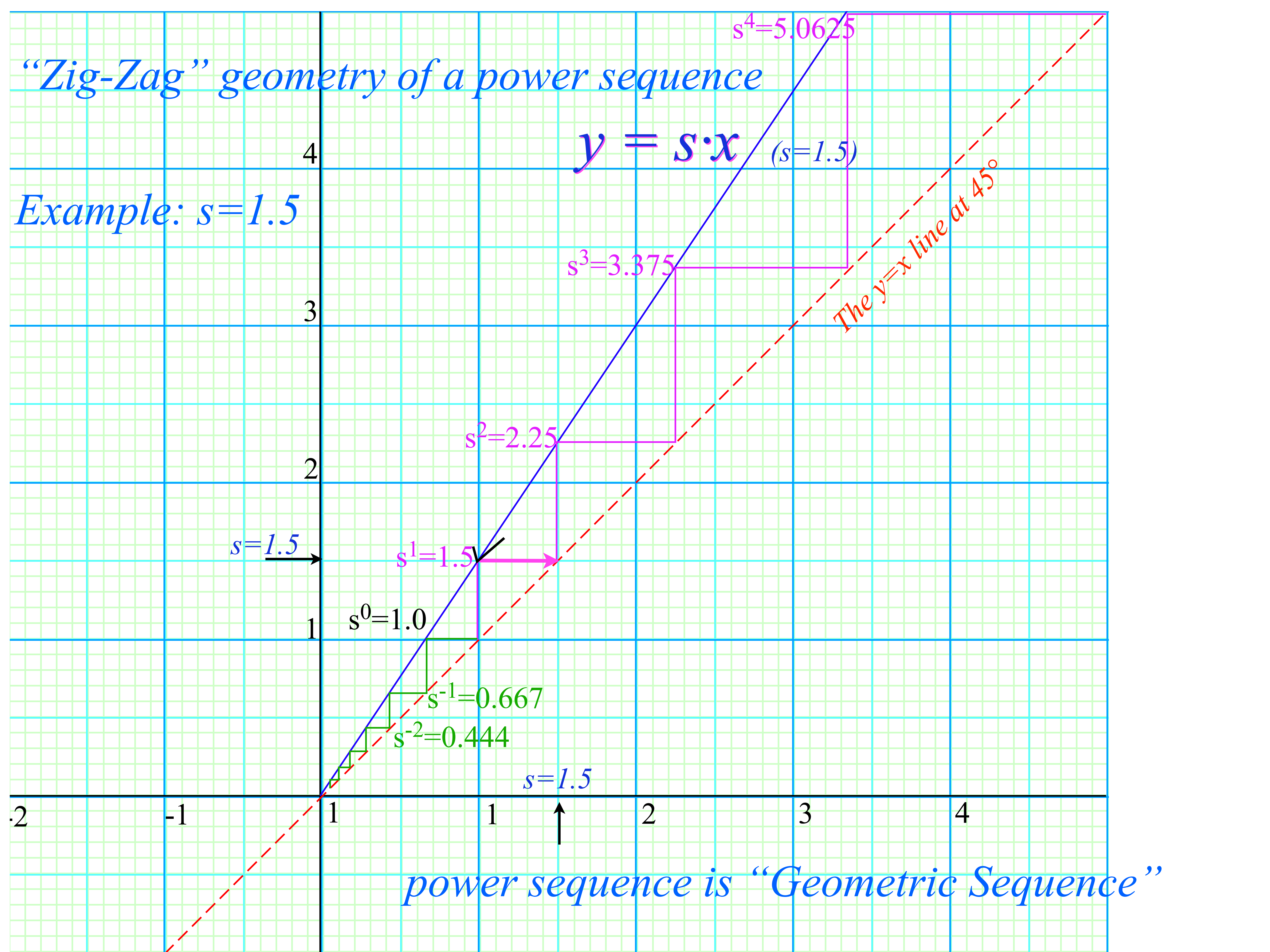




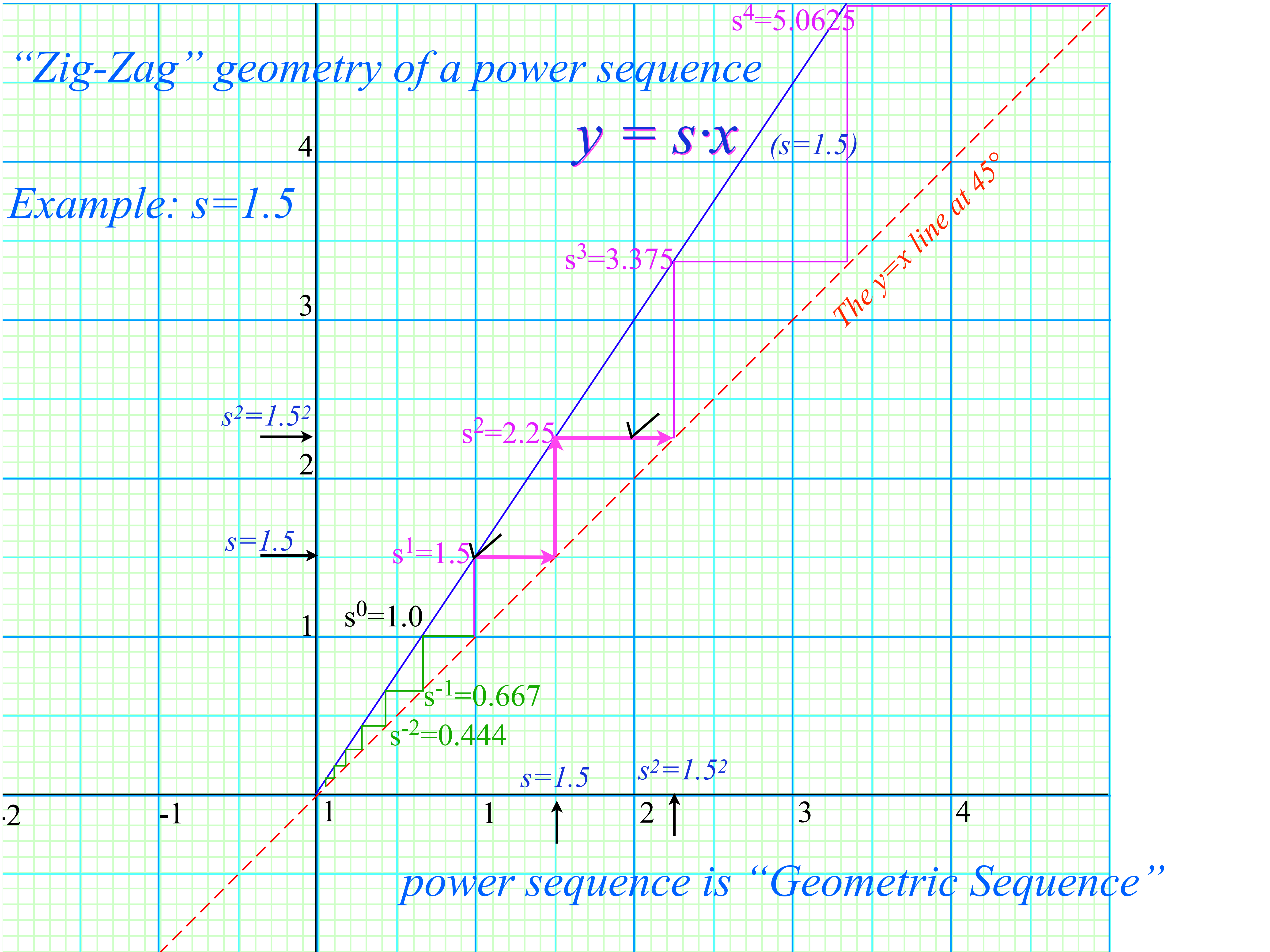
“Zig-Zag” geometry of a power sequence
y = s·x
(s=1.5)
Example: s=1.5
The y=x line at 45°
s³=3.375
s²=2.25
s¹=1.5
s=1.5
s=1.5
4
3
2
1
-2
-1
1
2
3
4


"Zig-Zag" geometry of a power sequence
y = s·x (s=1.5)
Example: s=1.5
The y=x line at 45°
s³=3.375
s²=2.25
s¹=1.5
s=1.5
s=1.5
4
3
2
1
-2
-1
1
2
3
4

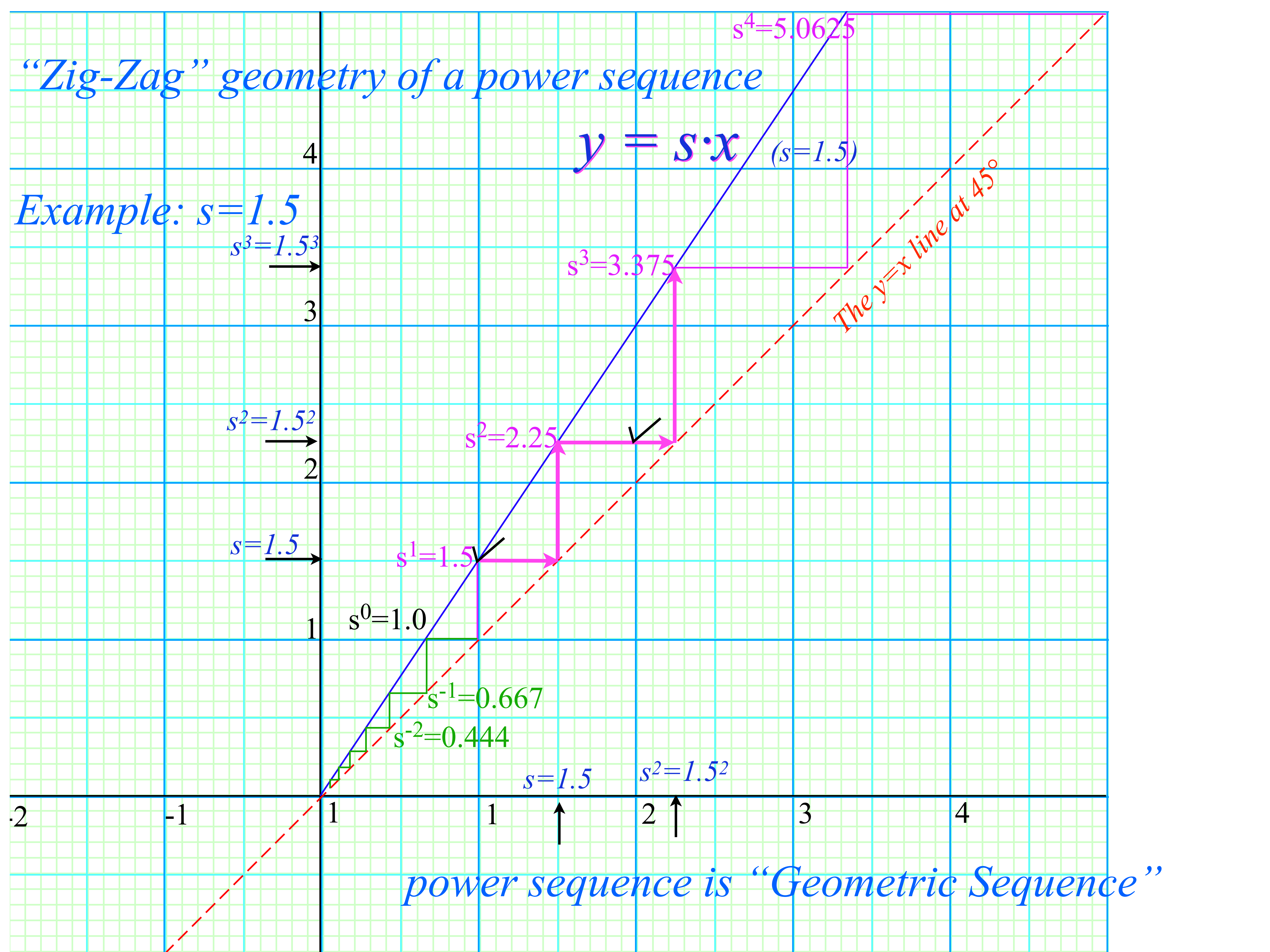

"Zig-Zag" geometry of a power sequence
y = s·x
(s=1.5)
Example: s=1.5
s⁴=5.0625
s³=3.375
s²=2.25
s¹=1.5
s=1.5
The y=x line at 45°
s=1.5
-2
-1
1
2
3
4
1
2
3
4
power sequence is "Geometric Sequence"



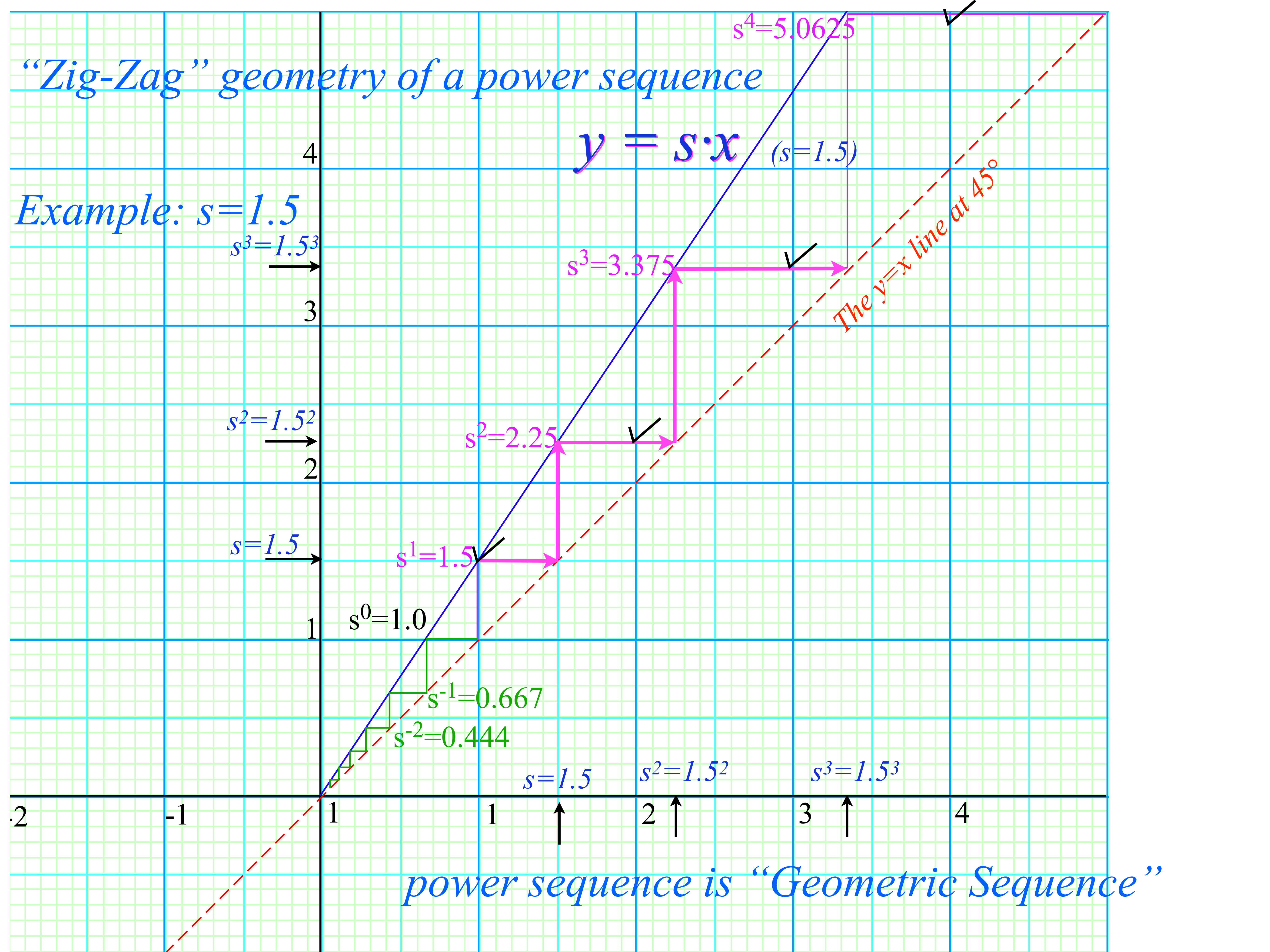
"Zig-Zag" geometry of a power sequence
y = s·x (s=1.5)
Example: s=1.5
s^4=5.0625
s^3=3.375
s^2=2.25
s^1=1.5
s^0=1.0
s^-1=0.667
s^-2=0.444
s=1.5
s=1.5
The y=x line at 45°
4
3
2
1
-2
-1
1
1
2
3
4
power sequence is "Geometric Sequence"



"Zig-Zag" geometry of a power sequence
y = s·x
(s=1.5)
Example: s=1.5
s⁴=5.0625
s³=3.375
s²=1.5²
s²=2.25
s=1.5
s¹=1.5
s⁰=1.0
s⁻¹=0.667
s⁻²=0.444
The y=x line at 45°
s=1.5
s²=1.5²
4
3
2
1
-2
-1
1
1
2
3
4
power sequence is "Geometric Sequence"



"Zig-Zag" geometry of a power sequence
y = s·x (s=1.5)
Example: s=1.5
s⁴=5.0625
s³=1.5³
s³=3.375
s²=1.5²
s²=2.25
s=1.5
s¹=1.5
s⁰=1.0
s⁻¹=0.667
s⁻²=0.444
s=1.5
s²=1.5²
The y=x line at 45°
4
3
2
1
-2
-1
1
1
2
3
4
power sequence is "Geometric Sequence"


"Zig-Zag" geometry of a power sequence
y = s·x (s=1.5)
Example: s=1.5
s⁴=5.0625
s³=3.375
s²=2.25
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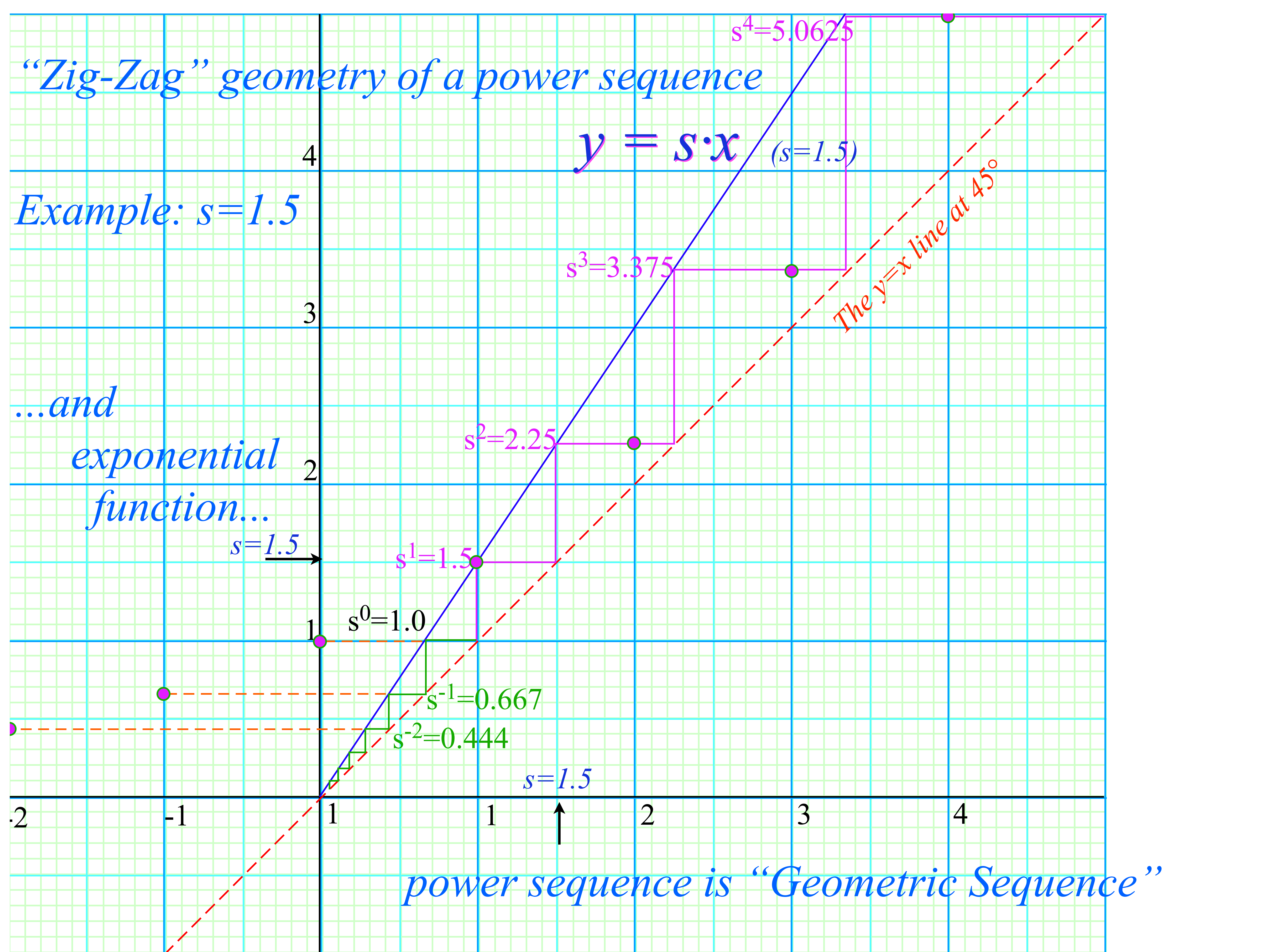
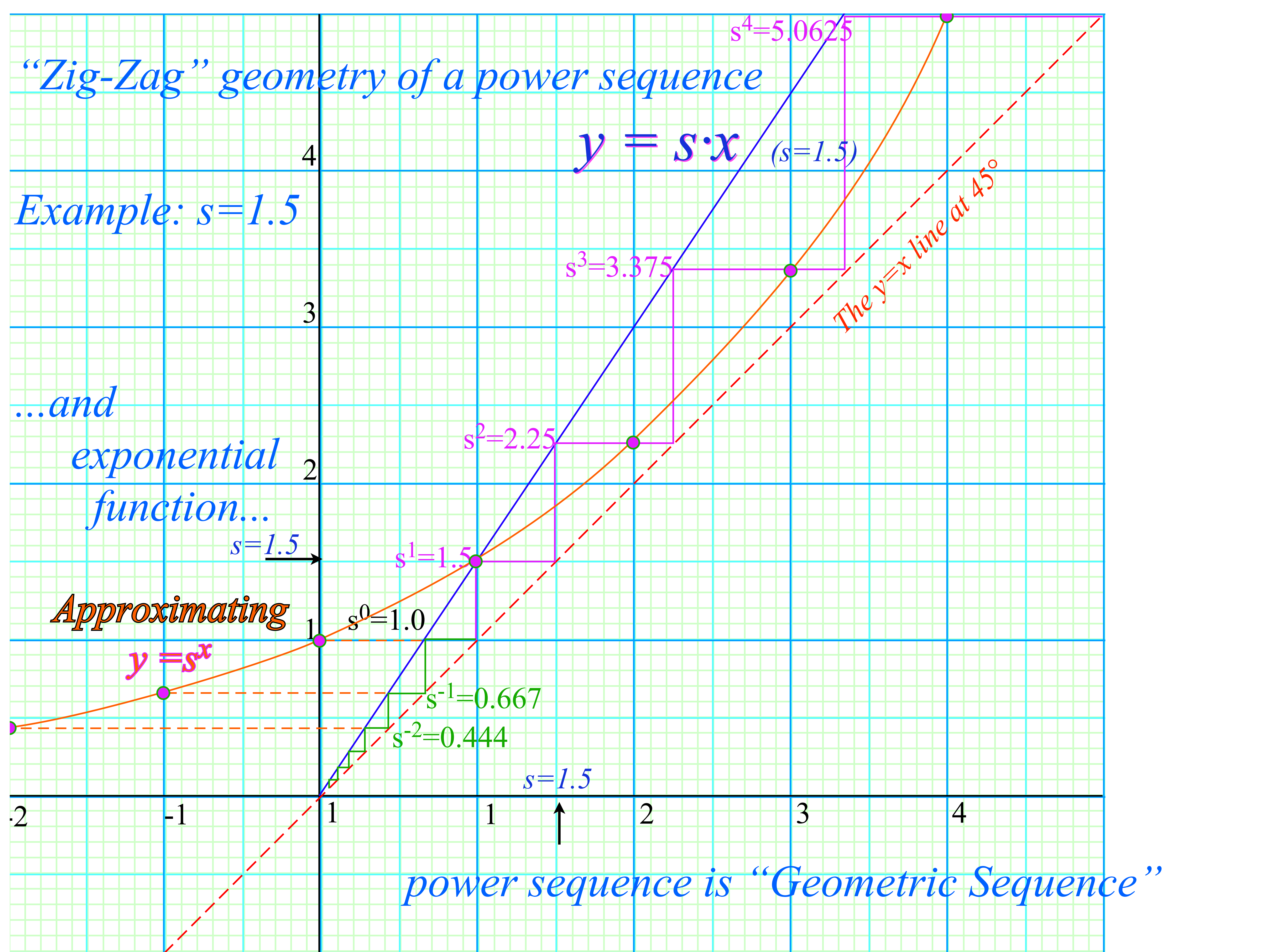
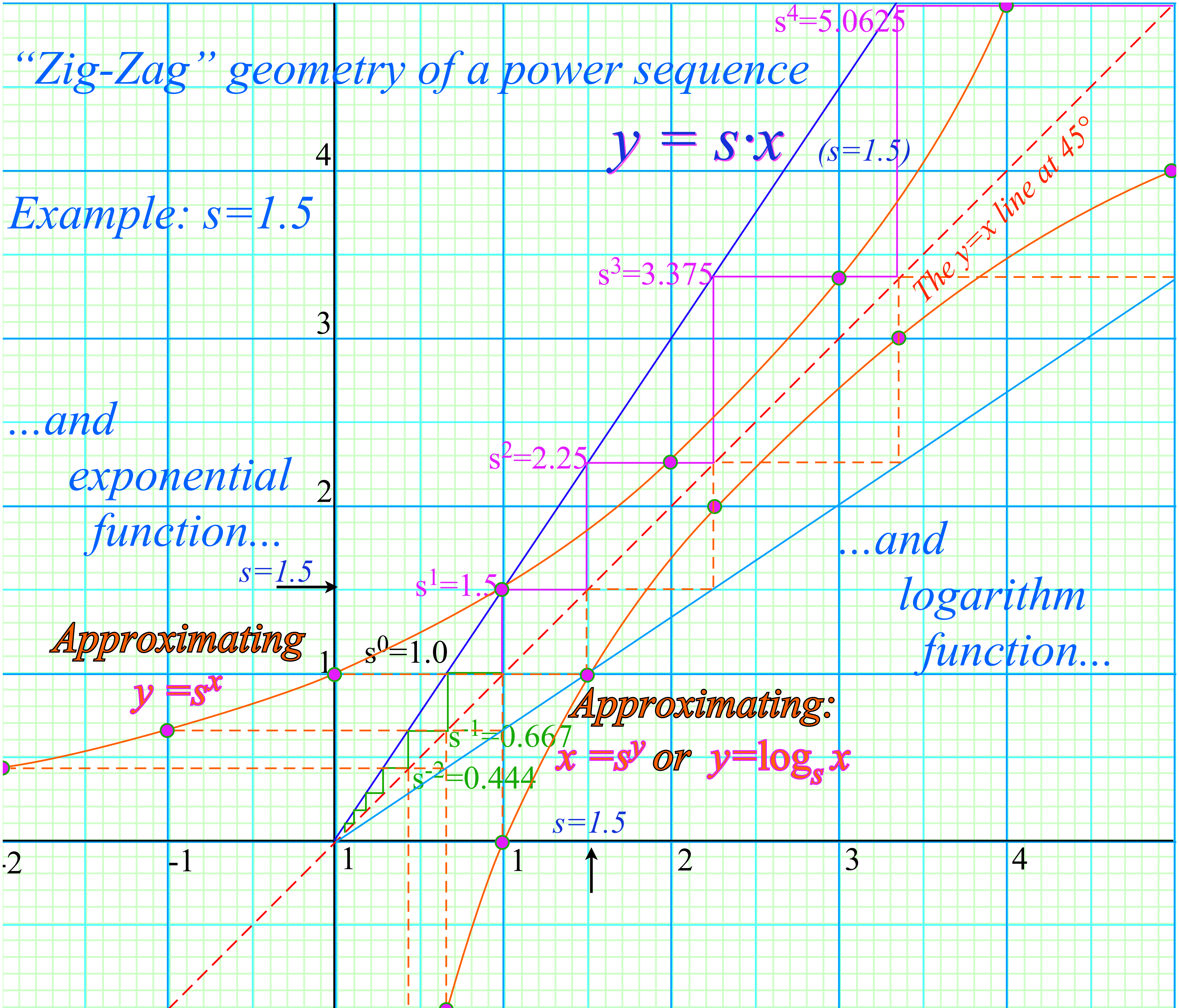
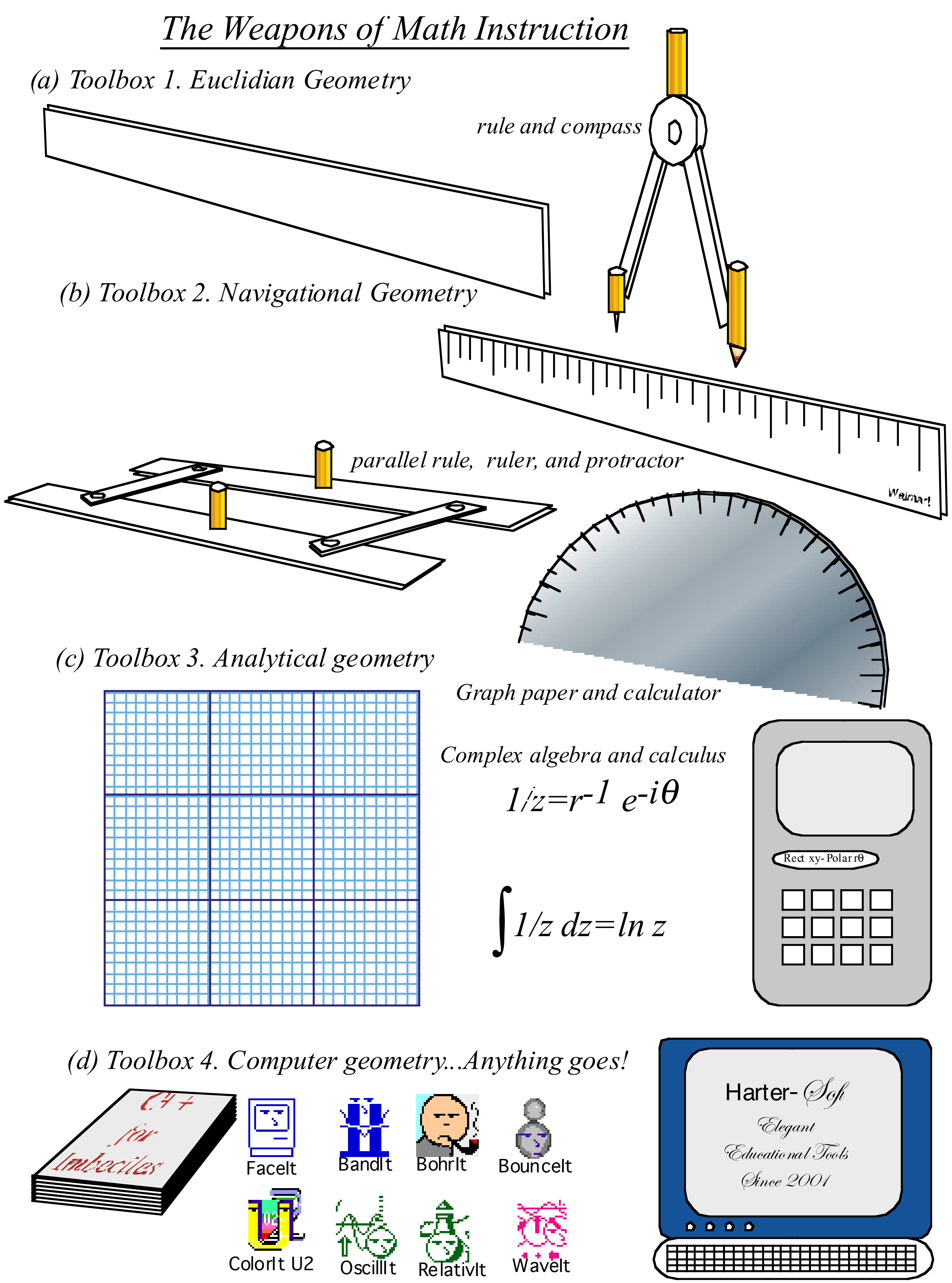
s⁰=1.0
s⁻¹=0.667
s⁻²=0.444
s³=1.5³
s²=1.5²
s=1.5
The y=x line at 45°
power sequence is "Geometric Sequence"


"Zig-Zag" geometry of a power sequence
y = s·x
(s=1.5)
Example: s=1.5
...and
exponential
function...
s=1.5
s⁴=5.0625
s³=3.375
s²=2.25
s¹=1.5
s⁰=1.0
s⁻¹=0.667
s⁻²=0.444
s=1.5
The y=x line at 45°
4
3
2
1
-2
-1
1
1
2
3
4
power sequence is "Geometric Sequence"


"Zig-Zag" geometry of a power sequence
Example: s=1.5
...and
exponential
function...
Approximating
y =s^x
y = s·x (s=1.5)
The y=x line at 45°
s^4=5.0625
s^3=3.375
s^2=2.25
s^1=1.5
s^0=1.0
s^-1=0.667
s^-2=0.444
s=1.5
s=1.5
4
3
2
1
-2
-1
1
1
2
3
4
power sequence is "Geometric Sequence"



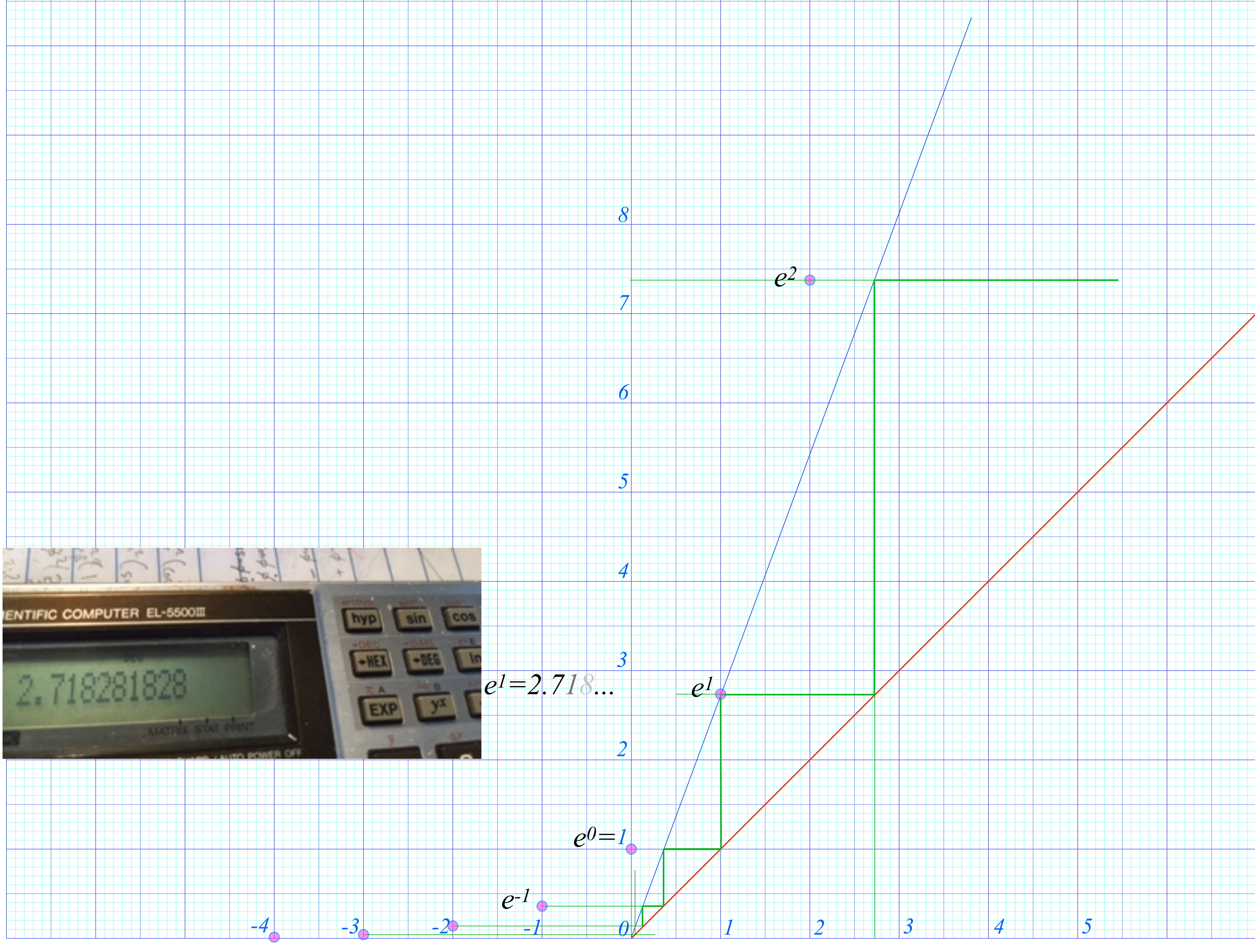
"Zig-Zag" geometry of a power sequence
y = s·x (s=1.5)
Example: s=1.5
...and exponential function...
...and logarithm function...
The y=x line at 45°
s⁴=5.0625
s³=3.375
s²=2.25
s¹=1.5
s⁰=1.0
s⁻¹=0.667
s⁻²=0.444
s=1.5
Approximating
y =sˣ
Approximating:
x =sʸ or y=logₛ x
s=1.5



So far we mostly use Toolbox (a-b)

What follows uses Toolbox (c) ...

...and Toolbox (d)



e2
e1=2.718...
e1
e0=1
e-1
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
1
2
3
4
5
ENTIFIC COMPUTER EL-5500III
2.718281828
hyp
sin
cos
→HEX
→DEG
EXP
yx

Geometry of common power-law potentials

Geometric (Power) series

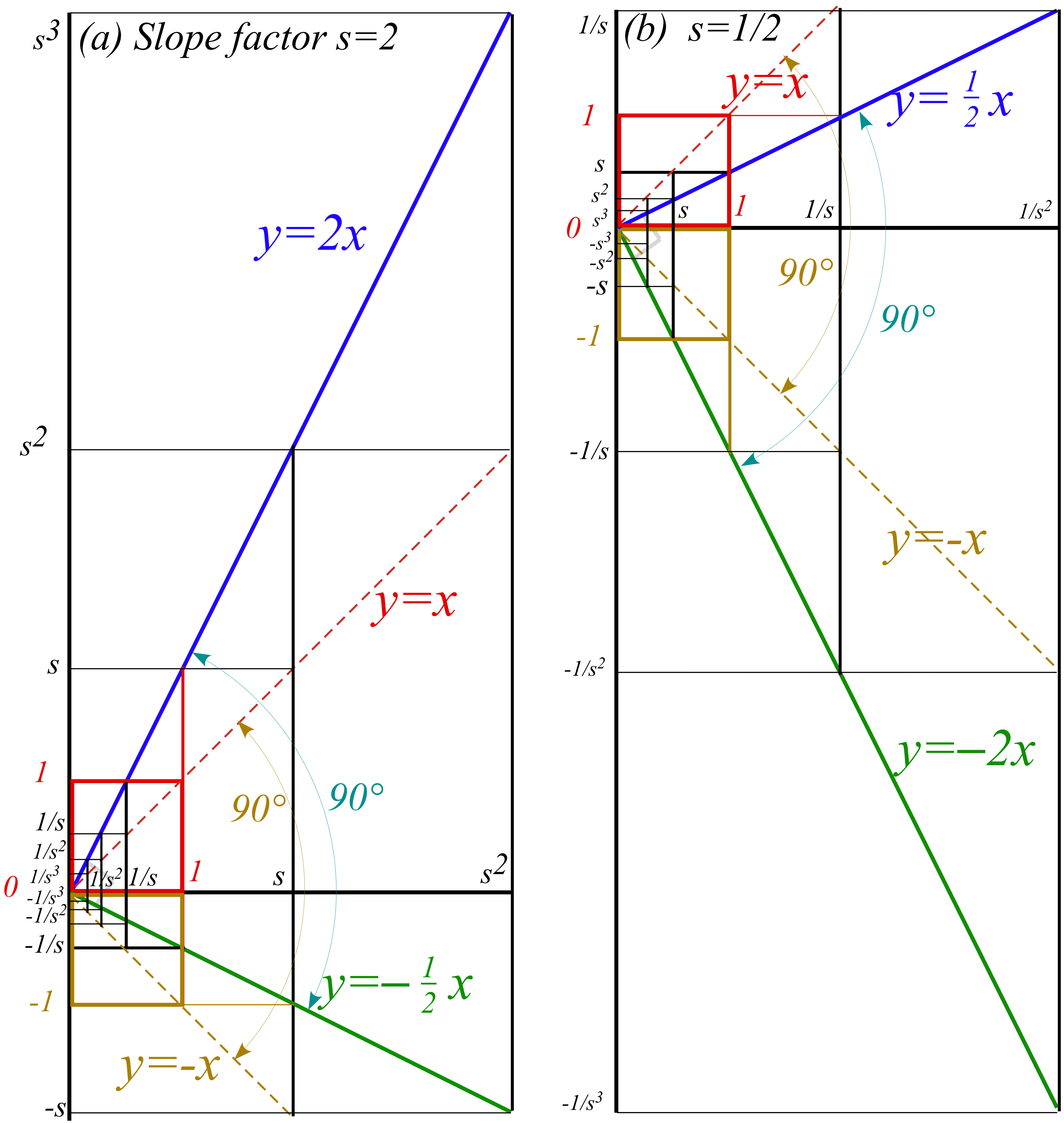
"Zig-Zag" exponential geometry

➡ *Projective or perspective geometry*

Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields

Coulomb geometry of $-1/r$-potential and $-1/r^2$-force fields

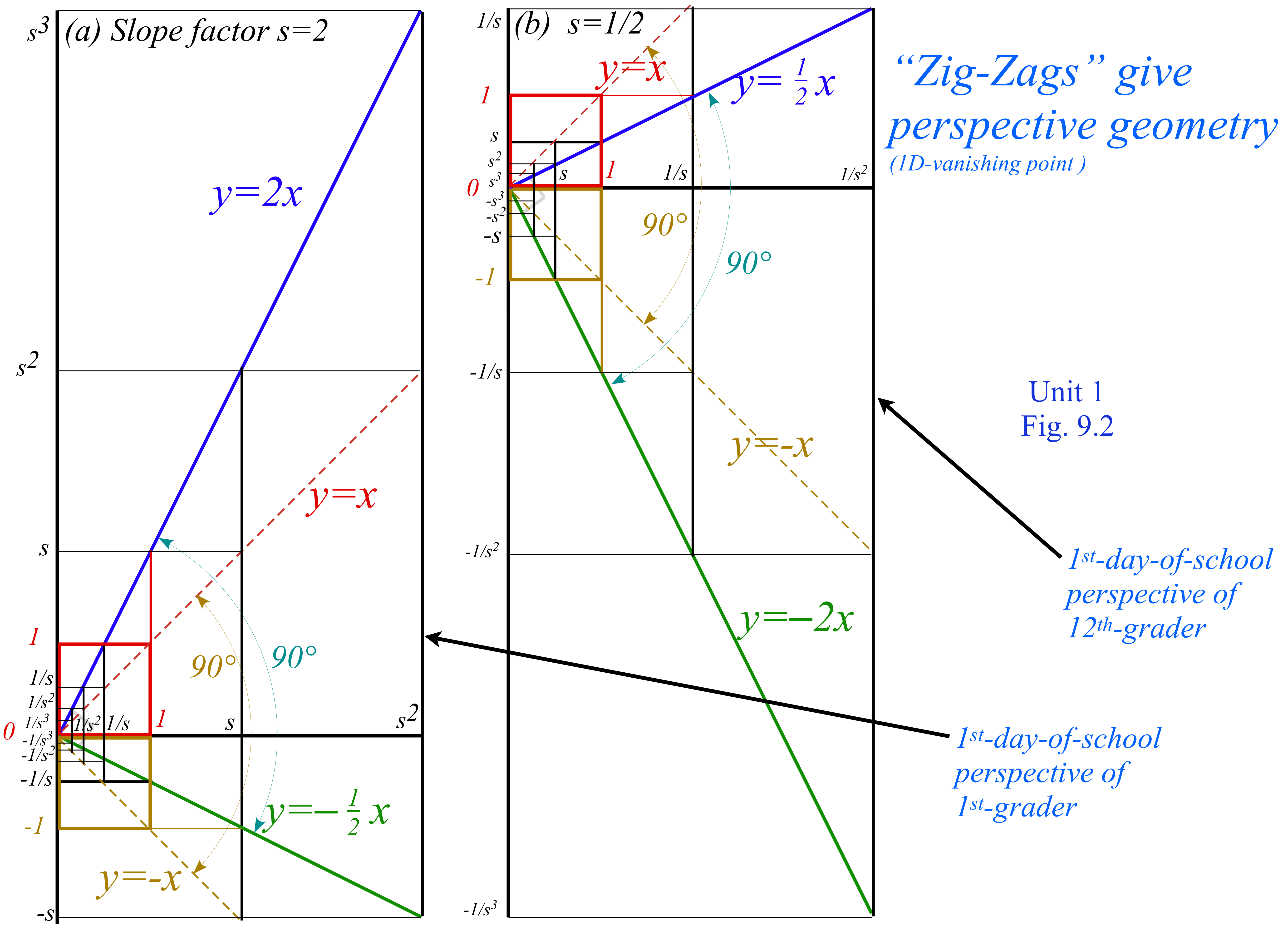
Compare mks units of Coulomb Electrostatic vs. Gravity



"Zig-Zags" give perspective geometry

(1D-vanishing point)

Unit 1
Fig. 9.2



(a) Slope factor s=2
y=2x
y=x
y=-x
y=-½ x
90°
90°
(b) s=1/2
y=x
y=½ x
y=-x
y=-2x
90°
90°
"Zig-Zags" give perspective geometry
(1D-vanishing point)
Unit 1
Fig. 9.2
1st-day-of-school perspective of 12th-grader
1st-day-of-school perspective of 1st-grader

Geometry of common power-law potentials

Geometric (Power) series

"Zig-Zag" exponential geometry

Projective or perspective geometry

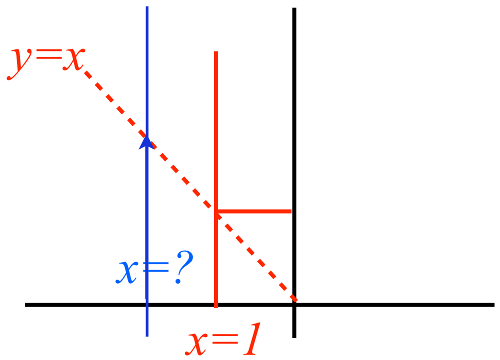
→ *Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields*

Coulomb geometry of $-1/r$-potential and $-1/r^2$-force fields

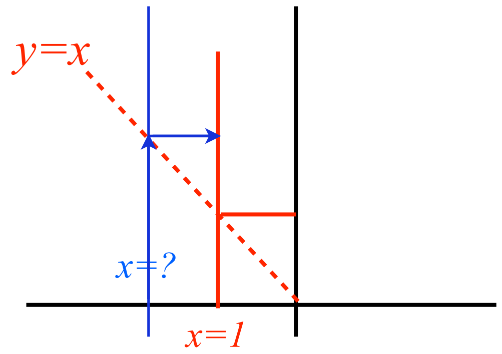
Compare mks units of Coulomb Electrostatic vs. Gravity

Each $y=x^2$ parabola point found by just one "Zig-Zag"

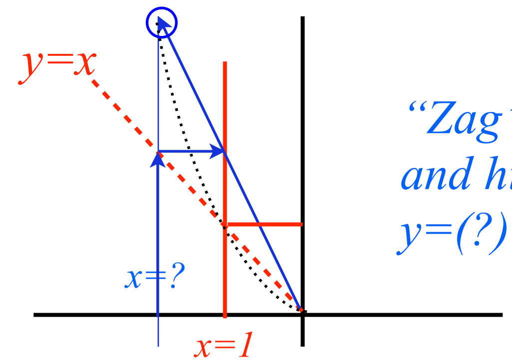
1. Pick an (x=?)-line



2. "Zig" from its y=x intersection to x=1 line



3. "Zag" from origin back to (x=?)-line



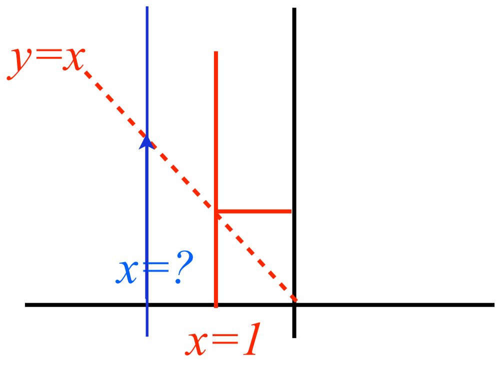
"Zag" line is $y=(?)\cdot x$ and hits (x=?)-line at $y=(?)\cdot(?)=(?)^2$

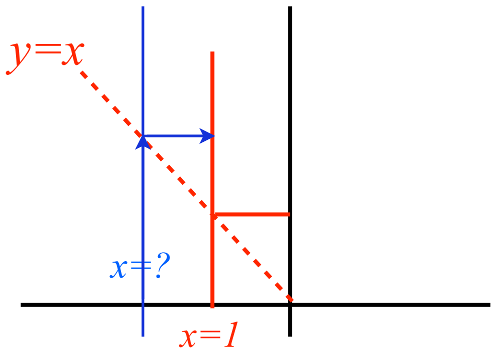
Each $y=x^2$ parabola point found by just one "Zig-Zag"

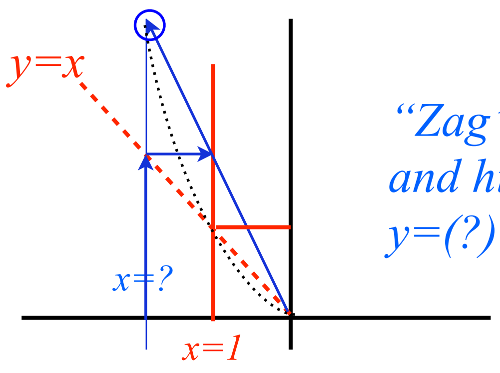
1. Pick an (x=?)-line

2. "Zig" from its y=x intersection to x=1 line

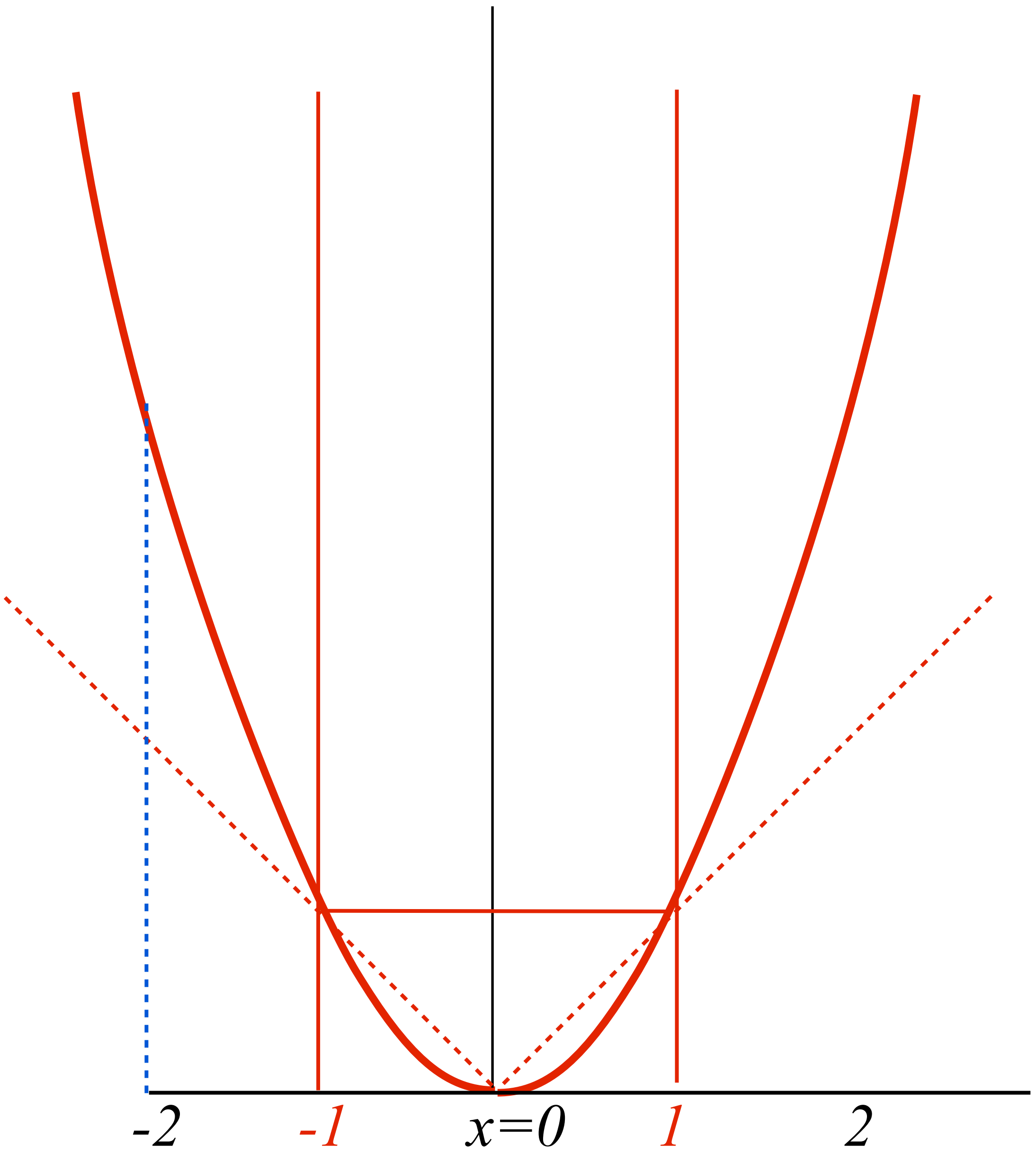
3. "Zag" from origin back to (x=?)-line







"Zag" line is y=(?)·x and hits (x=?)-line at y=(?)·(?)=(?)²



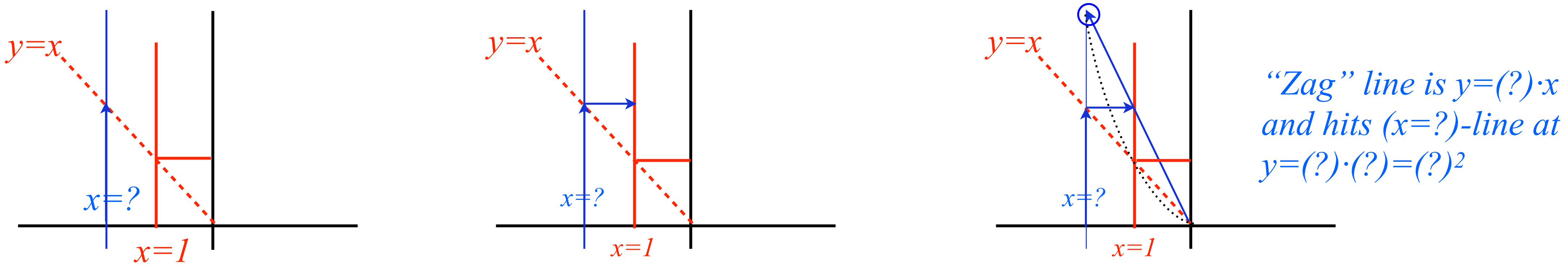
Unit 1
Fig. 9.1

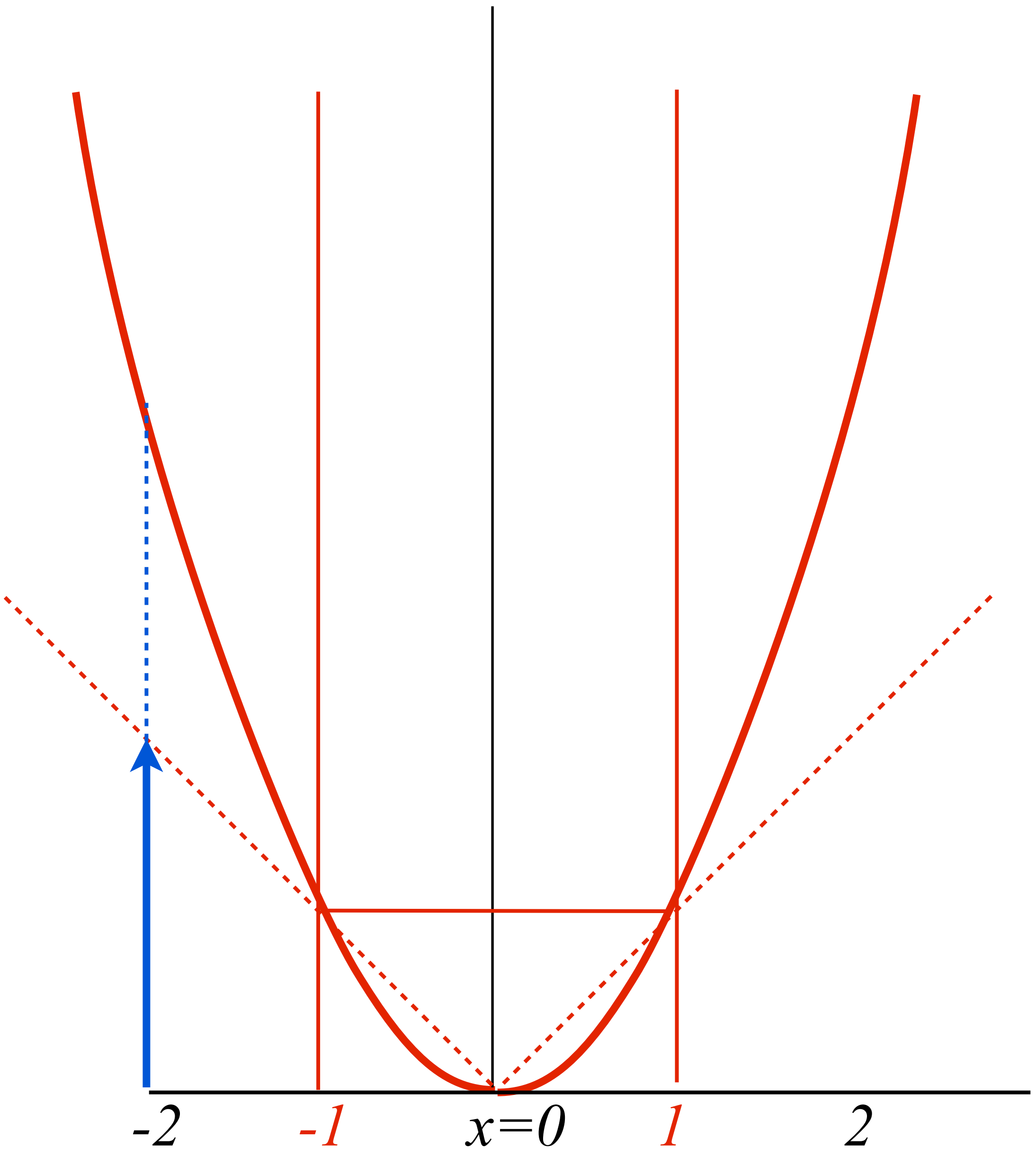
Each $y=x^2$ parabola point found by just one "Zig-Zag"

1. Pick an (x=?)-line

2. "Zig" from its y=x intersection to x=1 line

3. "Zag" from origin back to (x=?)-line





Unit 1
Fig. 9.1

Each $y=x^2$ parabola point found by just one "Zig-Zag"

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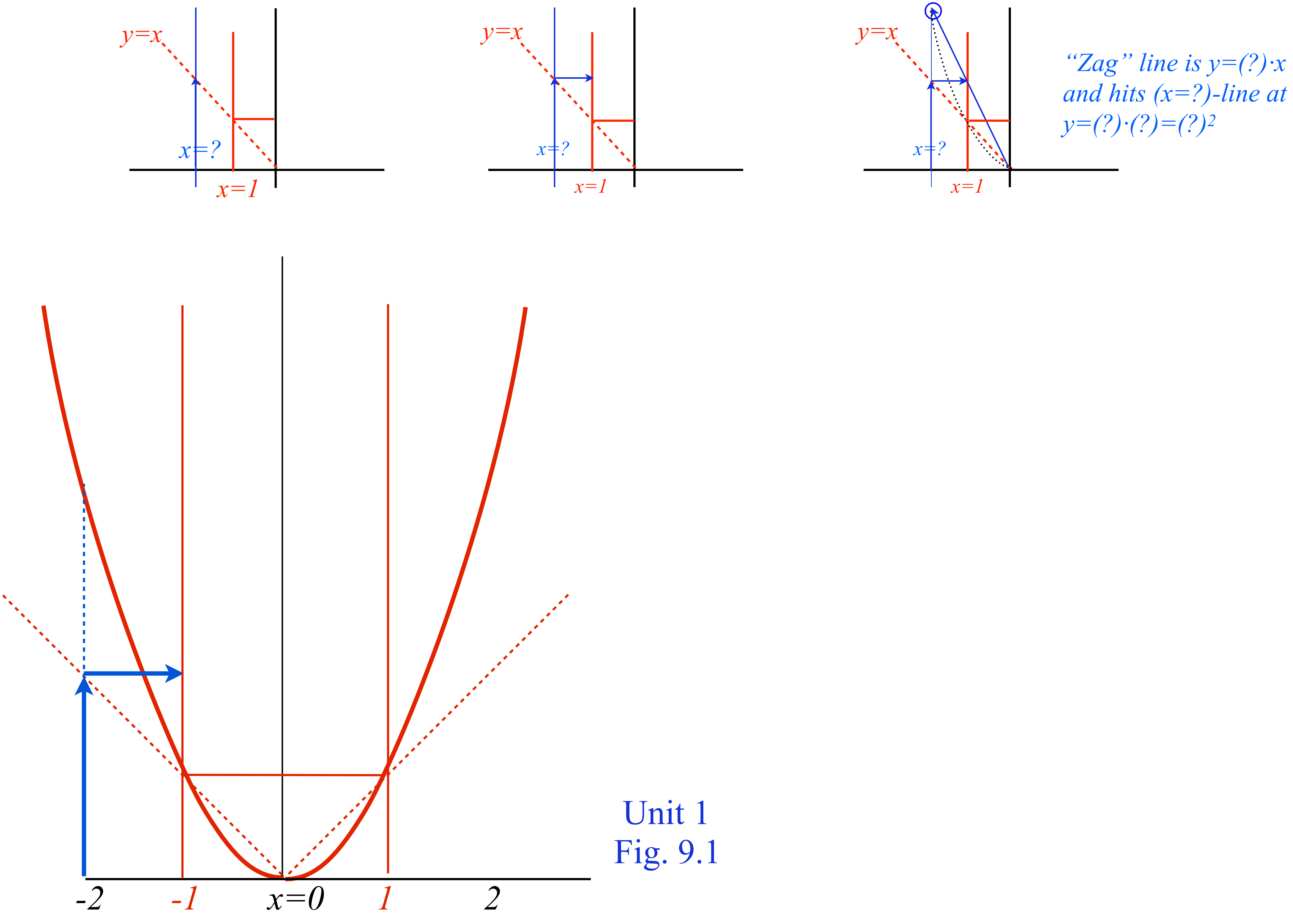

Unit 1
Fig. 9.1

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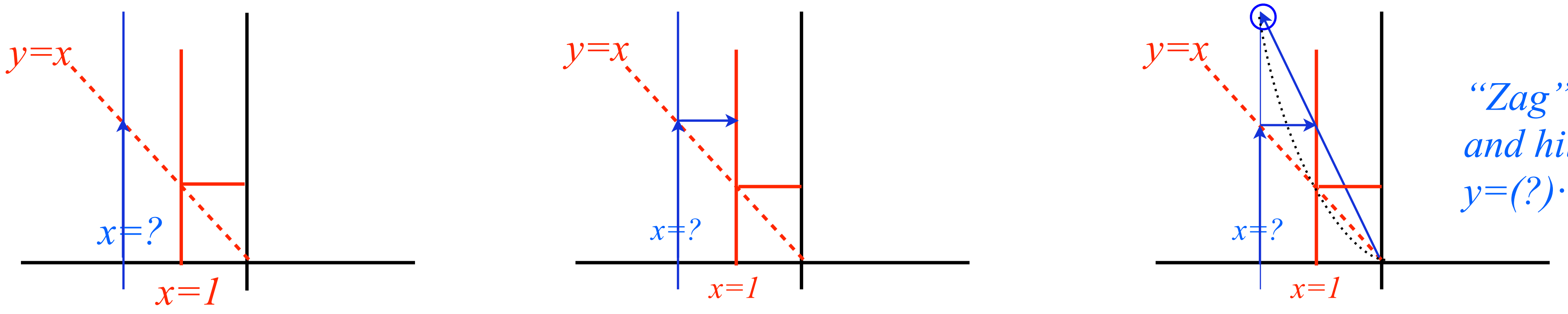
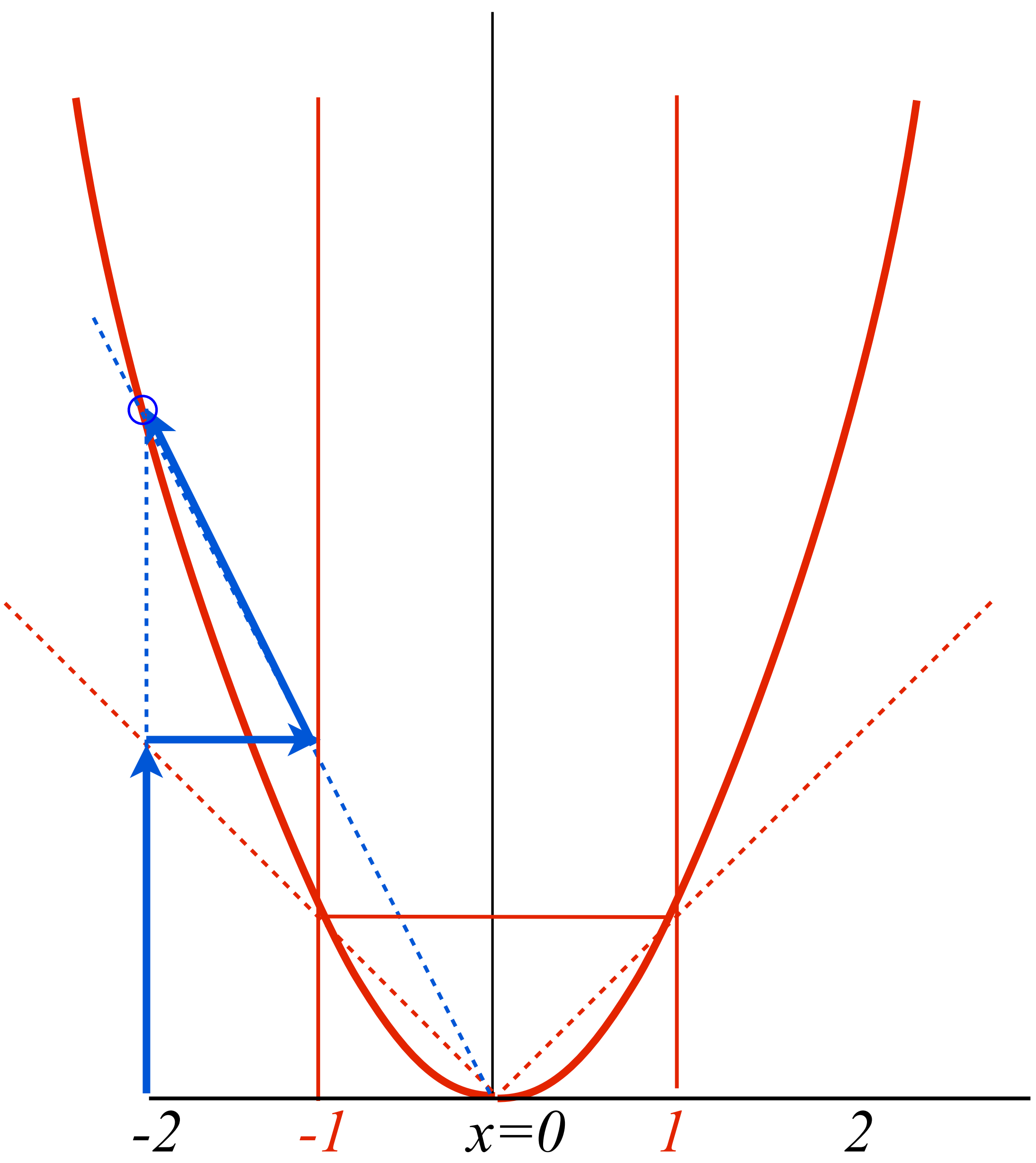


"Zag" line is $y=(?)\cdot x$ and hits (x=?)-line at $y=(?)\cdot(?)=(?)^2$



Unit 1
Fig. 9.1

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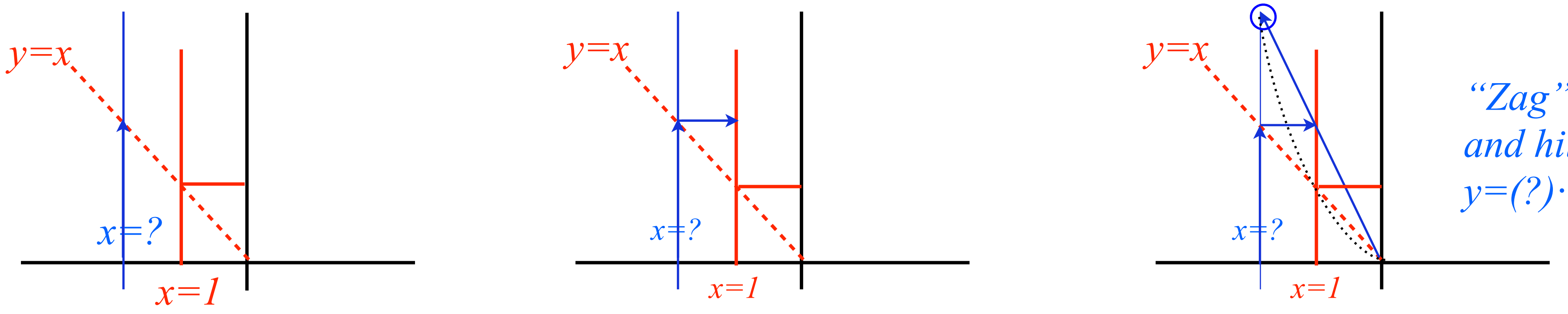

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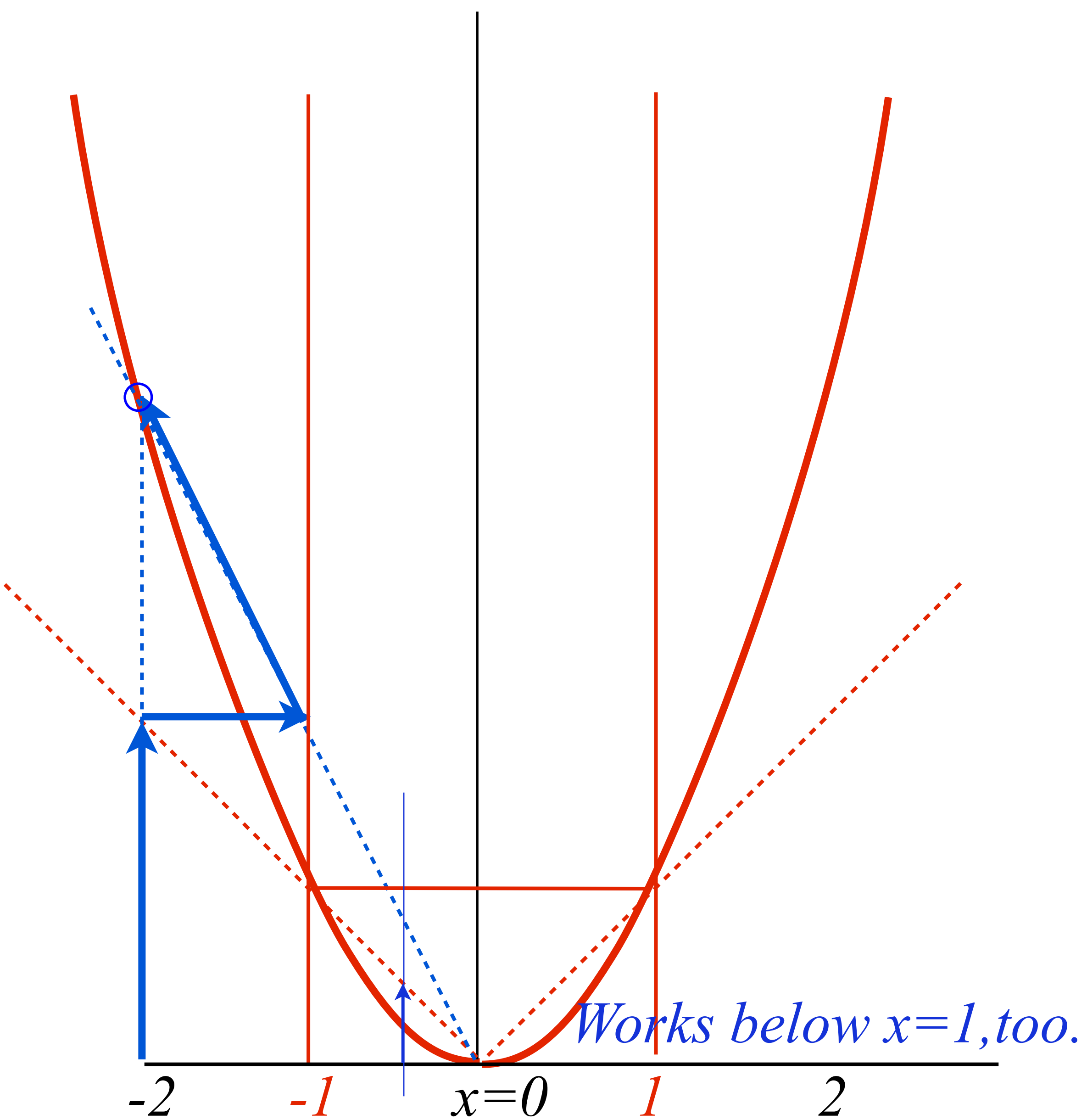

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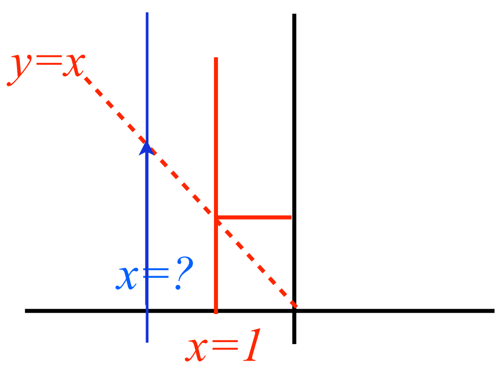
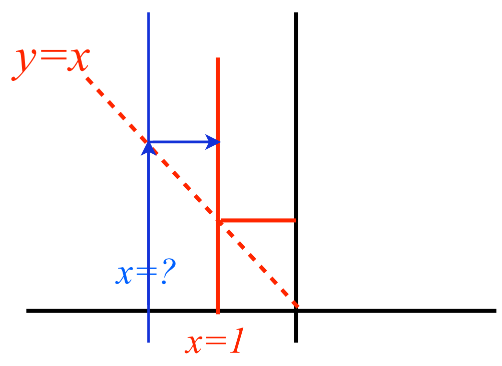
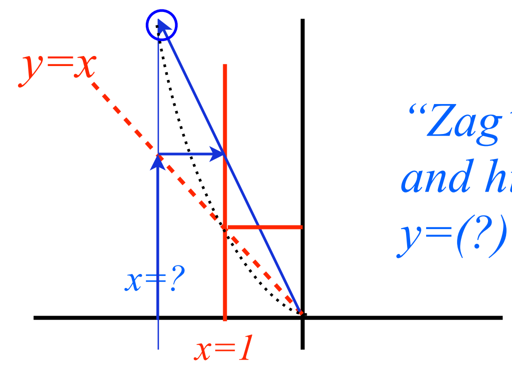
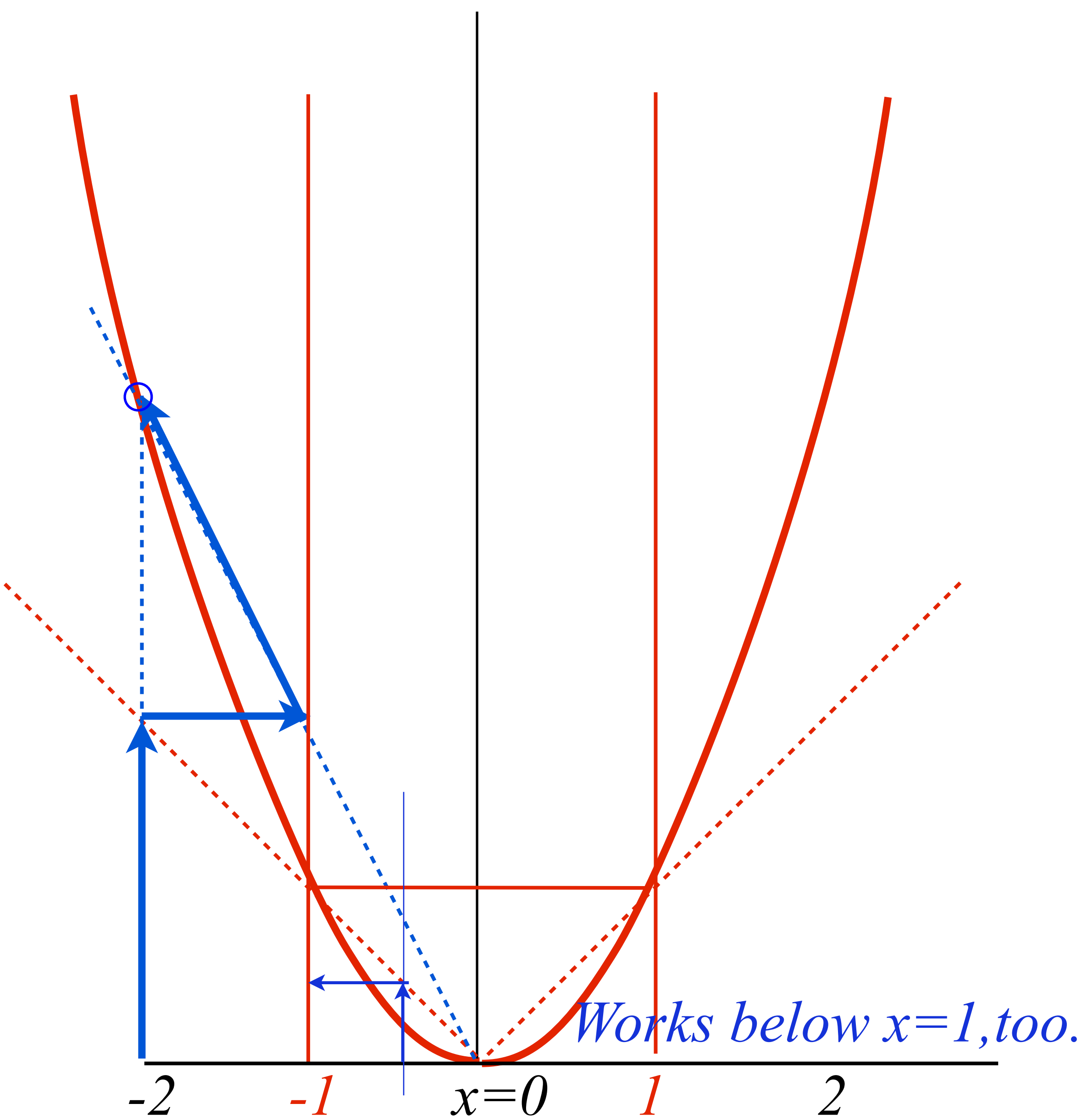






"Zag" line is $y=(?)\cdot x$ and hits (x=?)-line at $y=(?)\cdot(?)=(?)^2$



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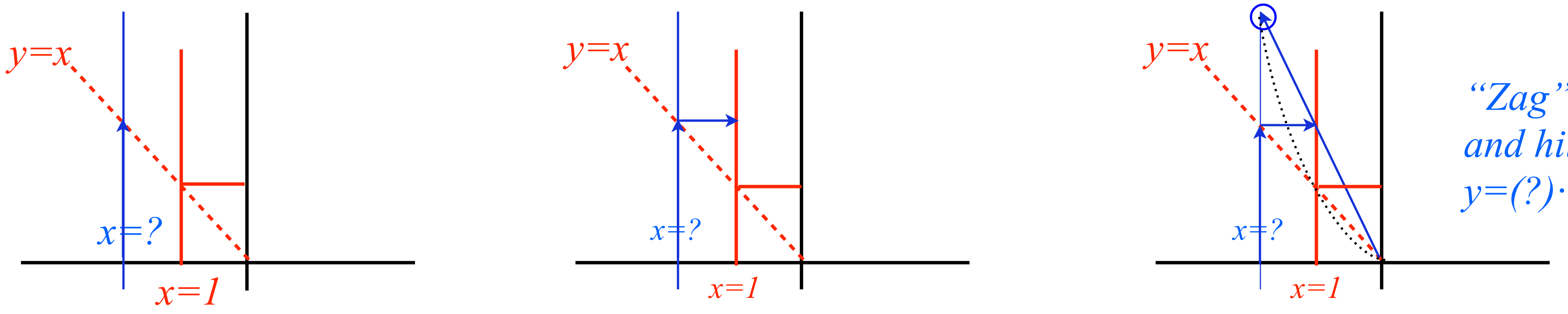

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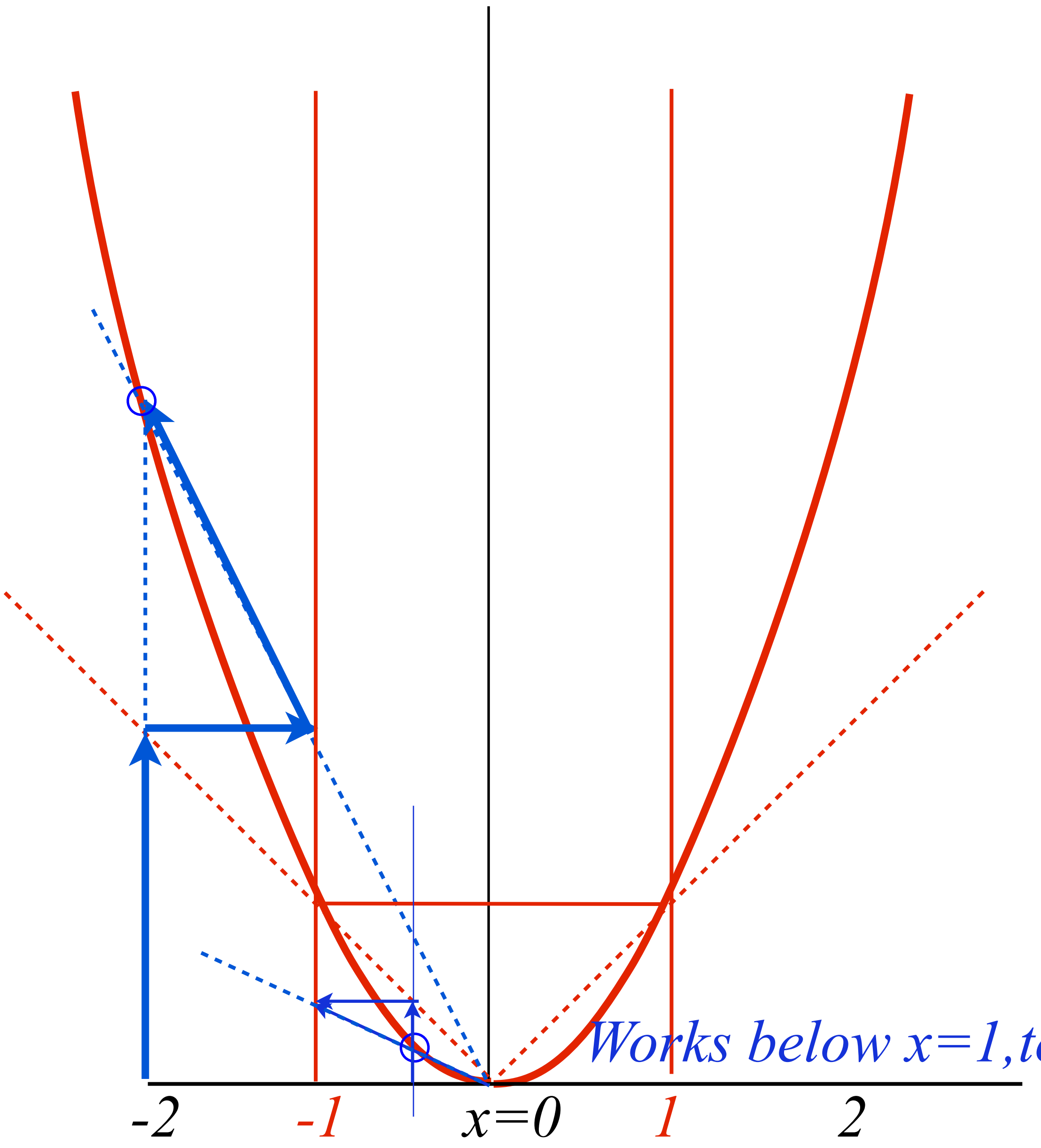

Unit 1
Fig. 9.1

Each $y=x^2$ parabola point found by just one "Zig-Zag"

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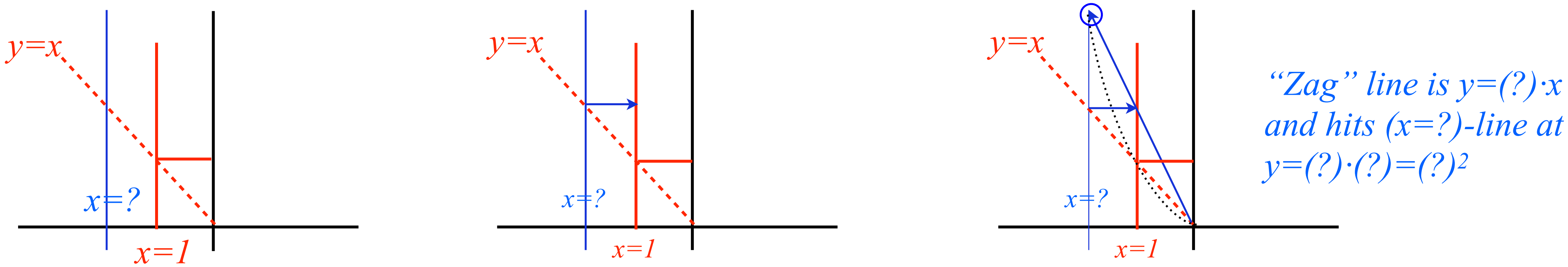
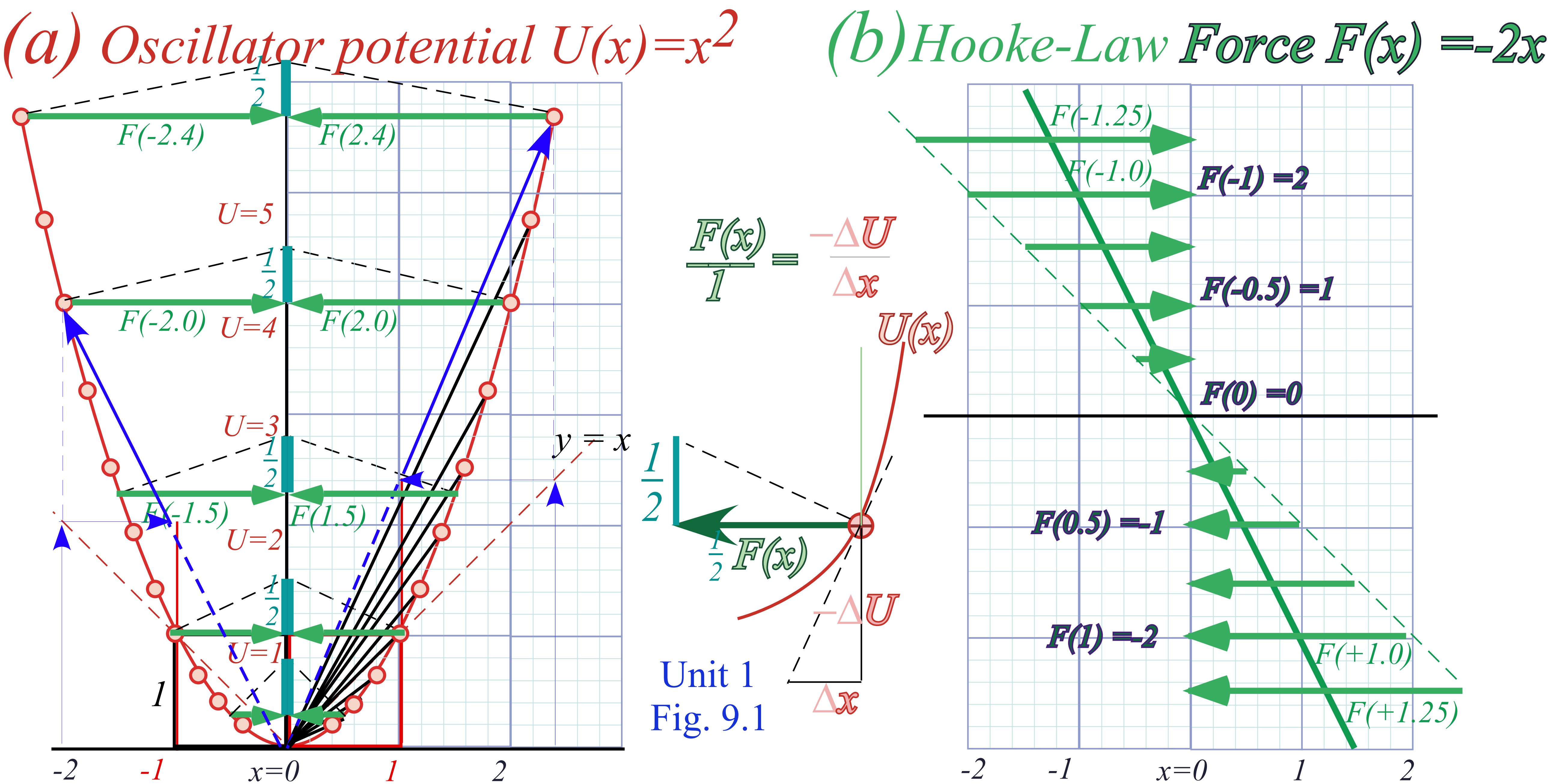
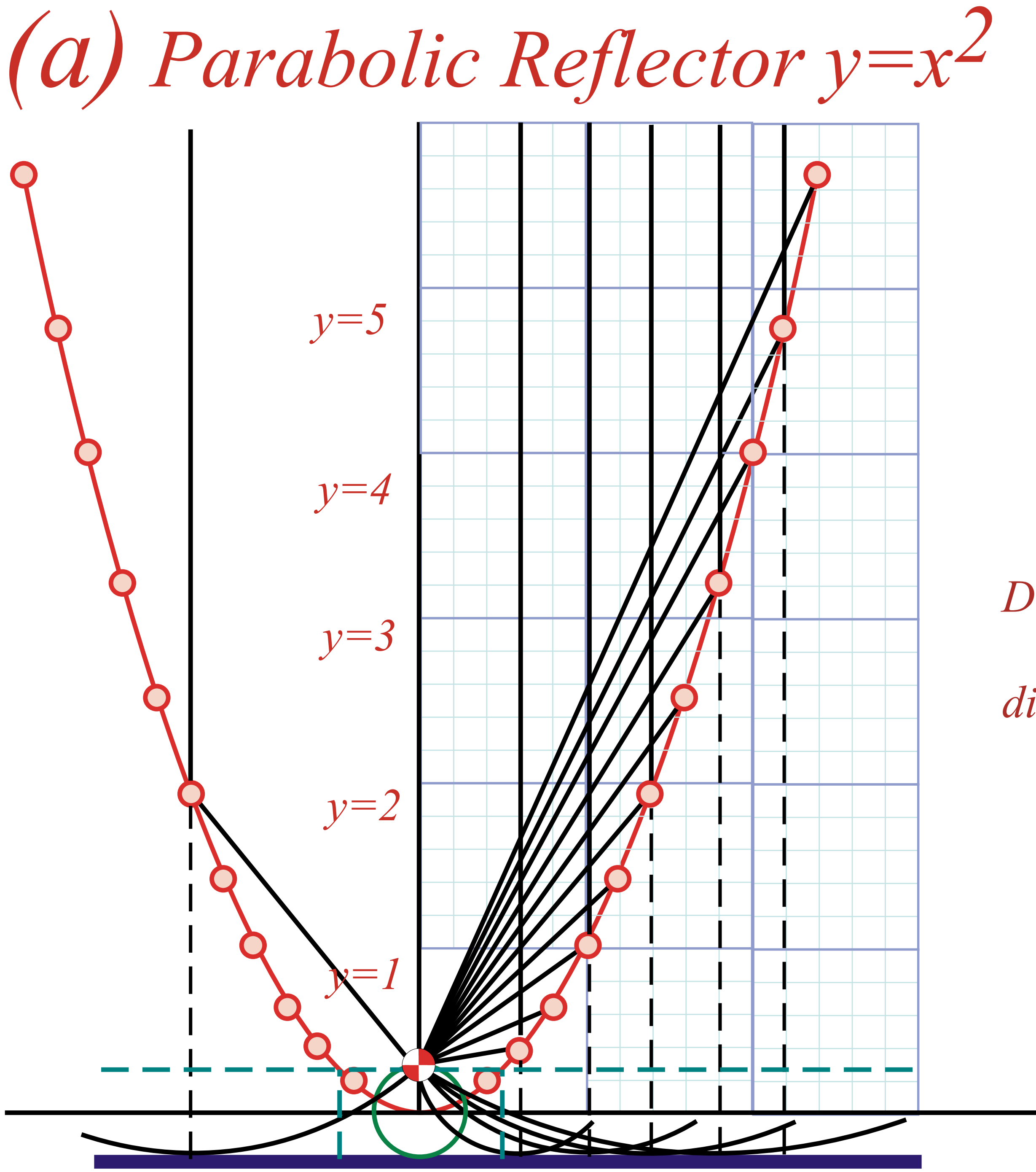
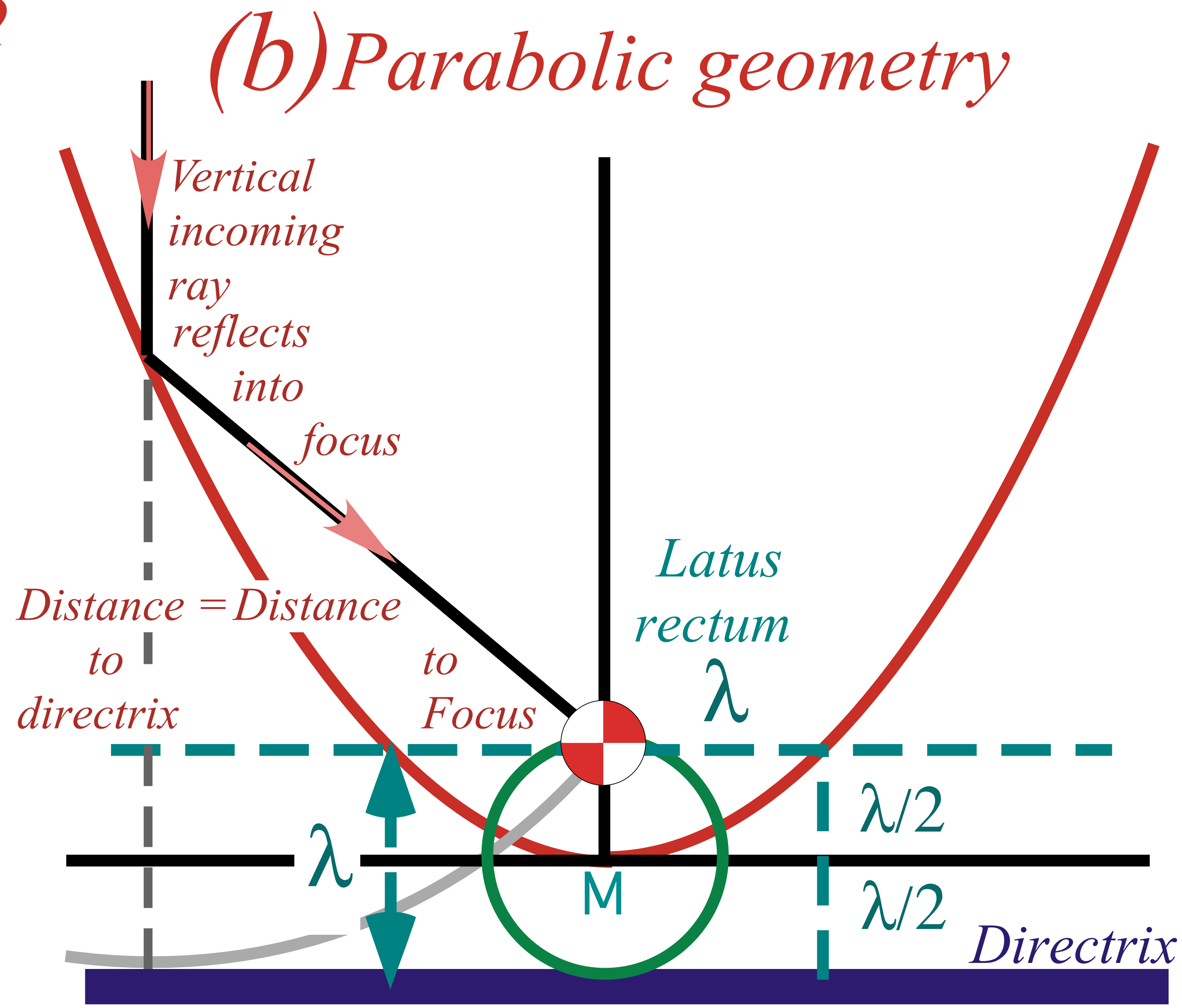




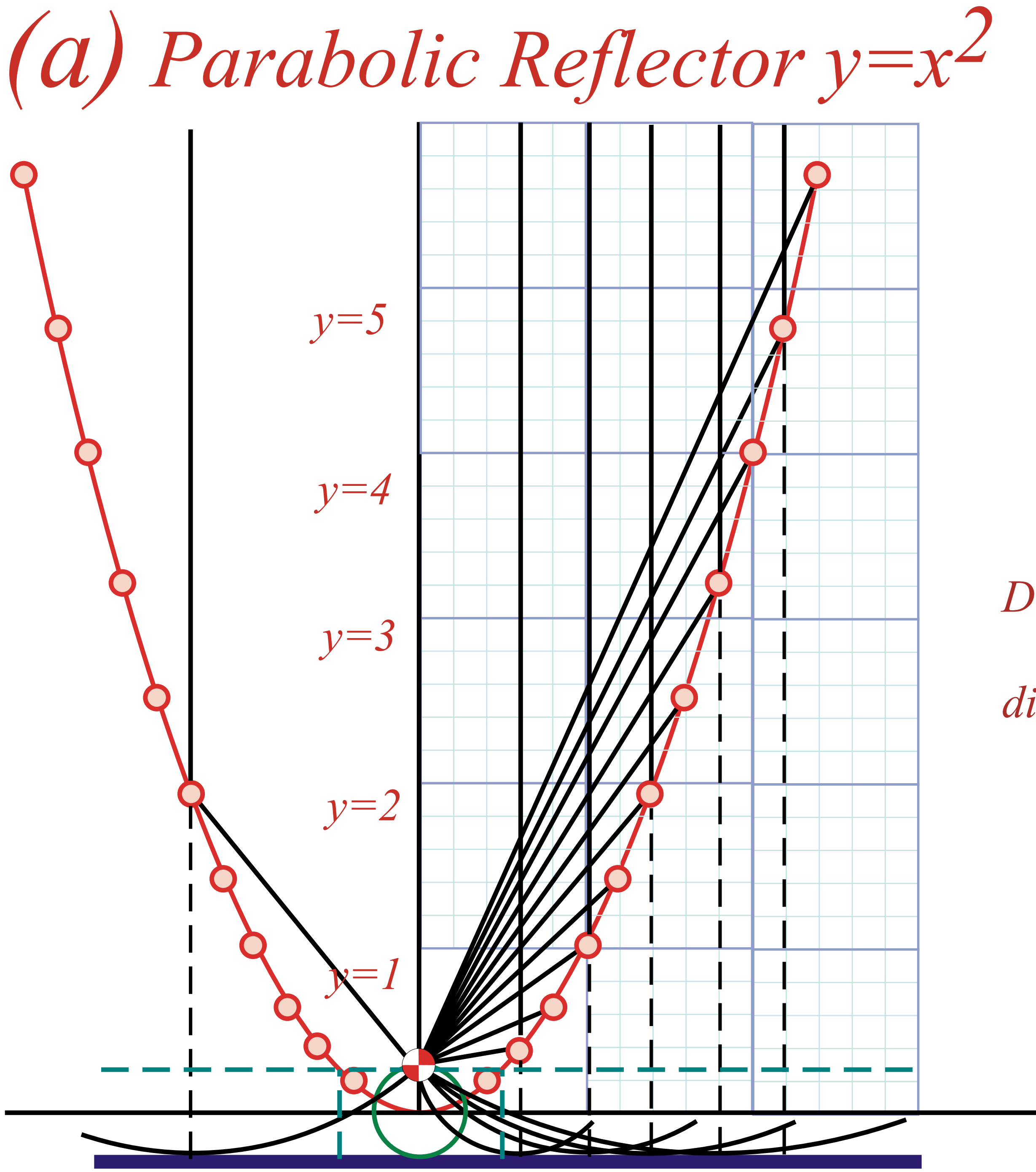
A more conventional parabolic geometry…(uses focal point)

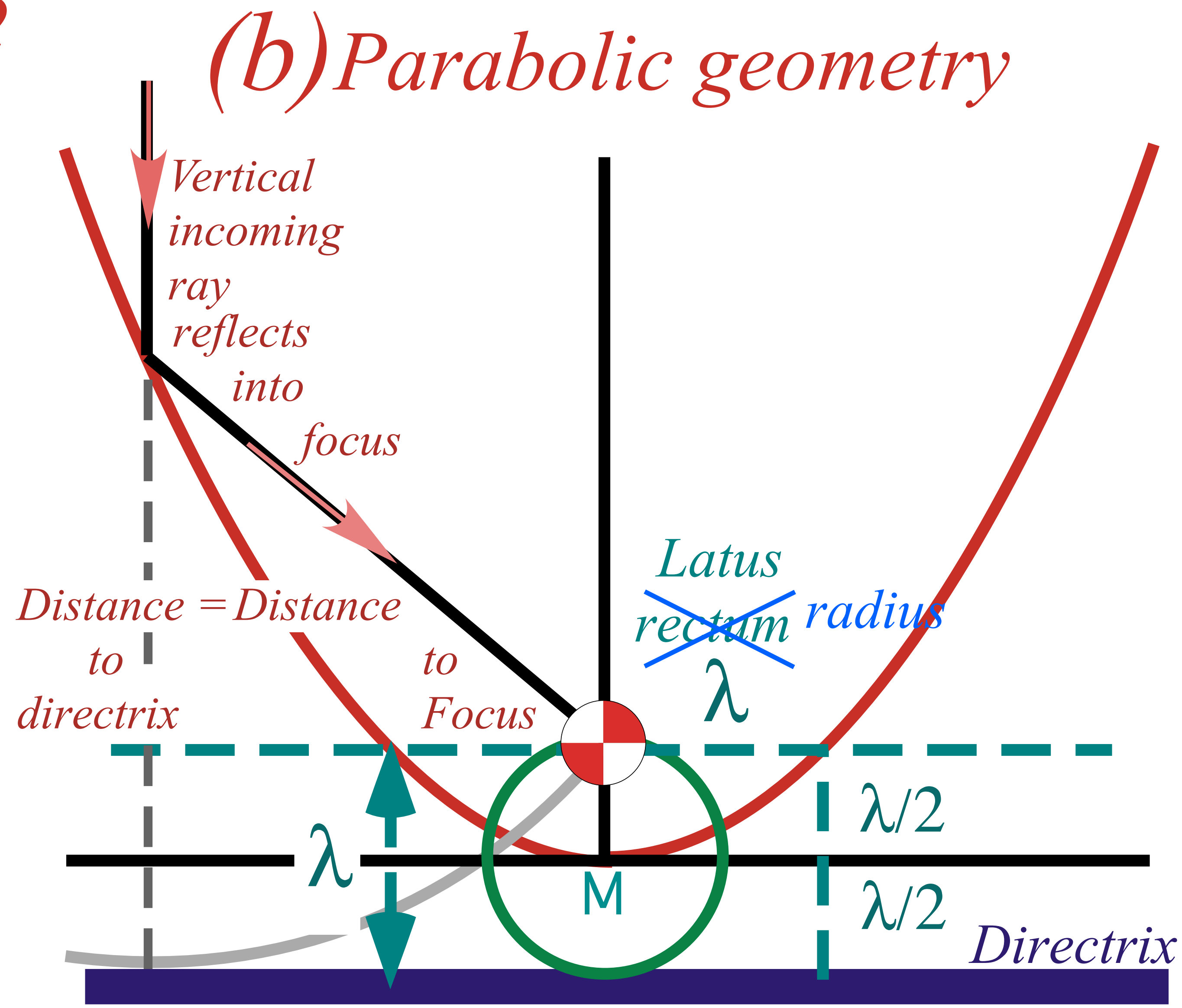




Unit 1
Fig. 9.3

A more conventional parabolic geometry...



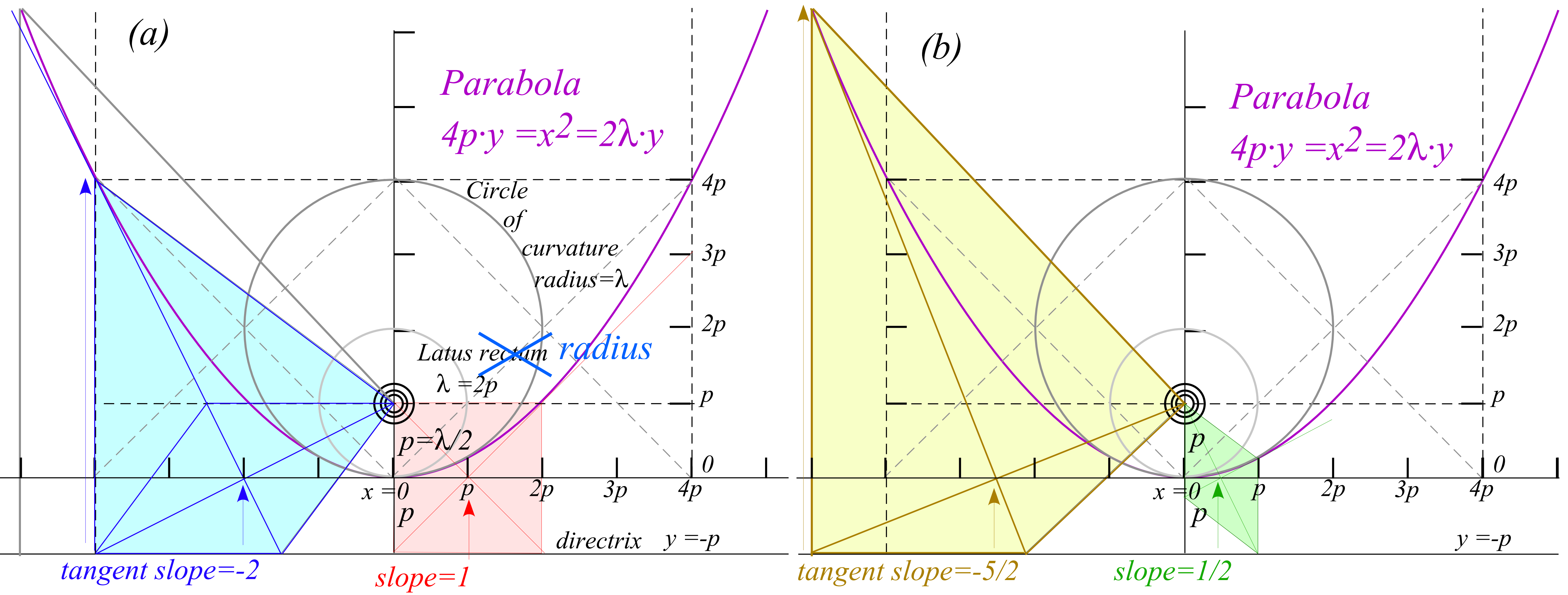


Better name† for λ : *latus radius*

†Old term *latus rectum* is exclusive copyright of
X-Treme Roidrage Gyms
Venice Beach, CA 90017

Unit 1
Fig. 9.3

...conventional parabolic geometry...carried to extremes...



Unit 1
Fig. 9.4

Geometry of common power-law potentials

Geometric (Power) series

"Zig-Zag" exponential geometry

Projective or perspective geometry

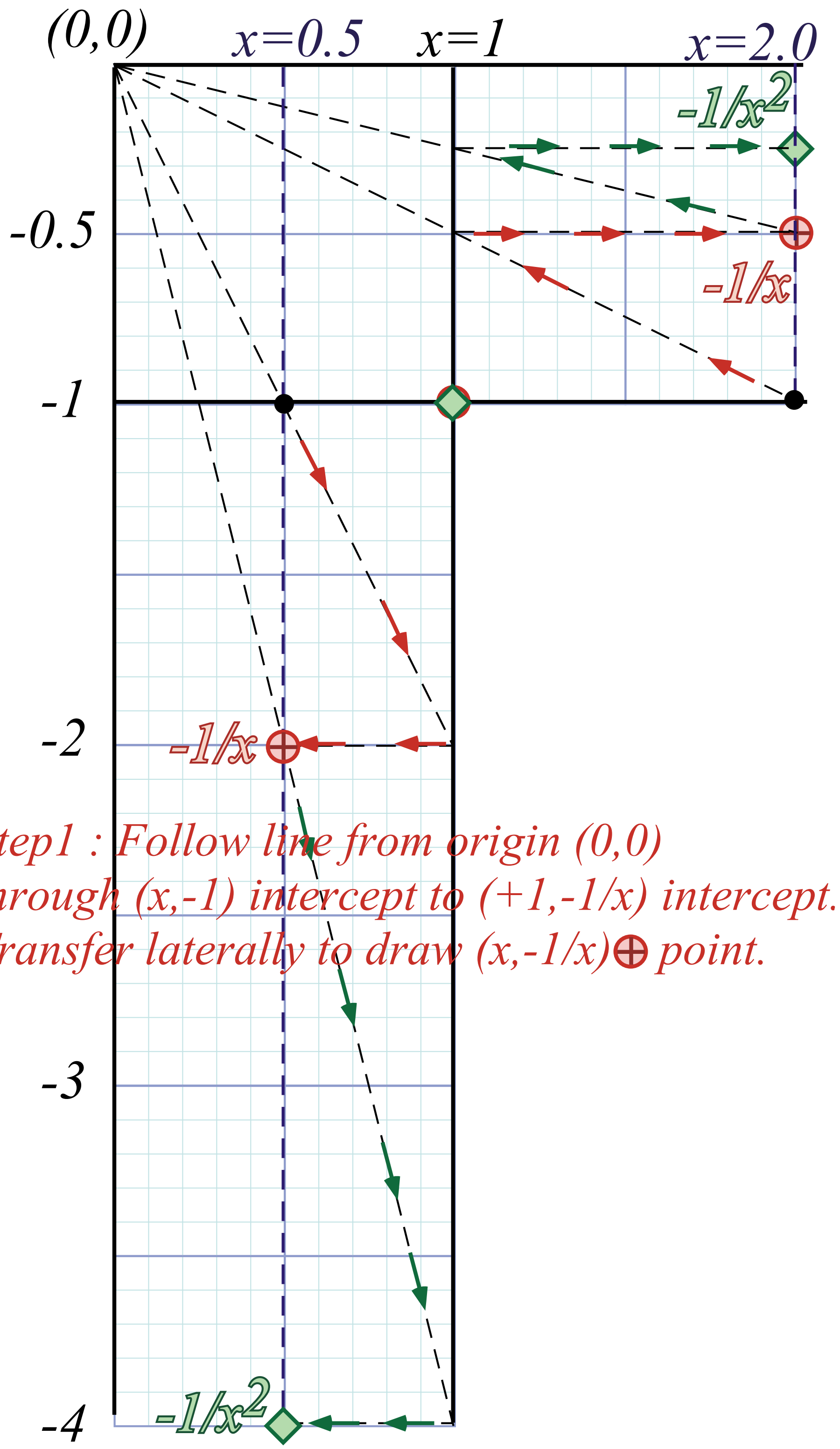
Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields

→ *Coulomb geometry of $-1/r$-potential and $-1/r^2$-force fields*

Compare mks units of Coulomb Electrostatic vs. Gravity

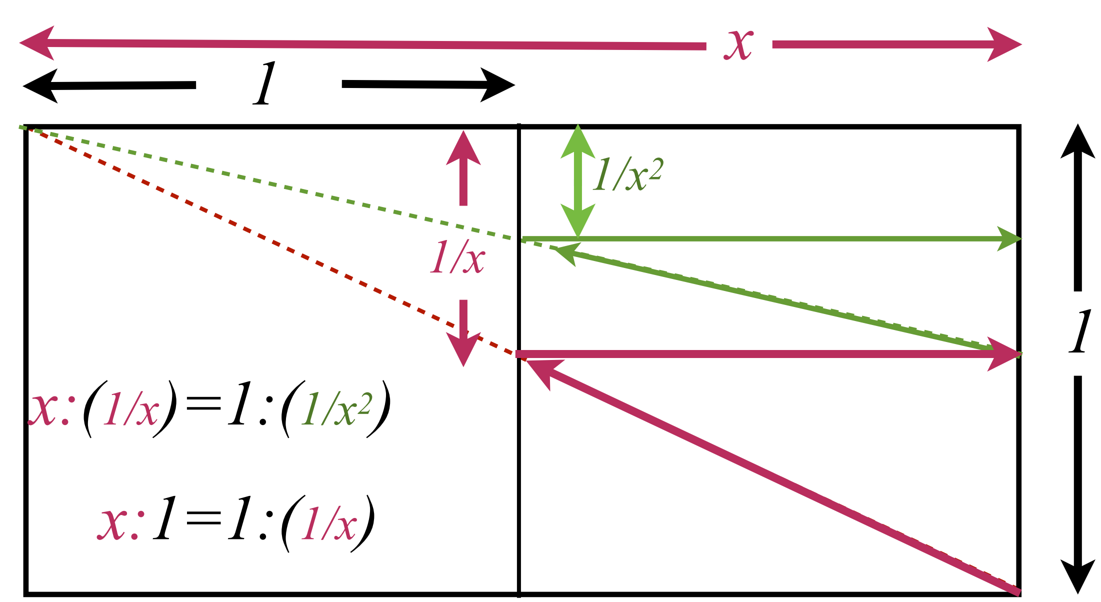
Unit 1
Fig. 9.4

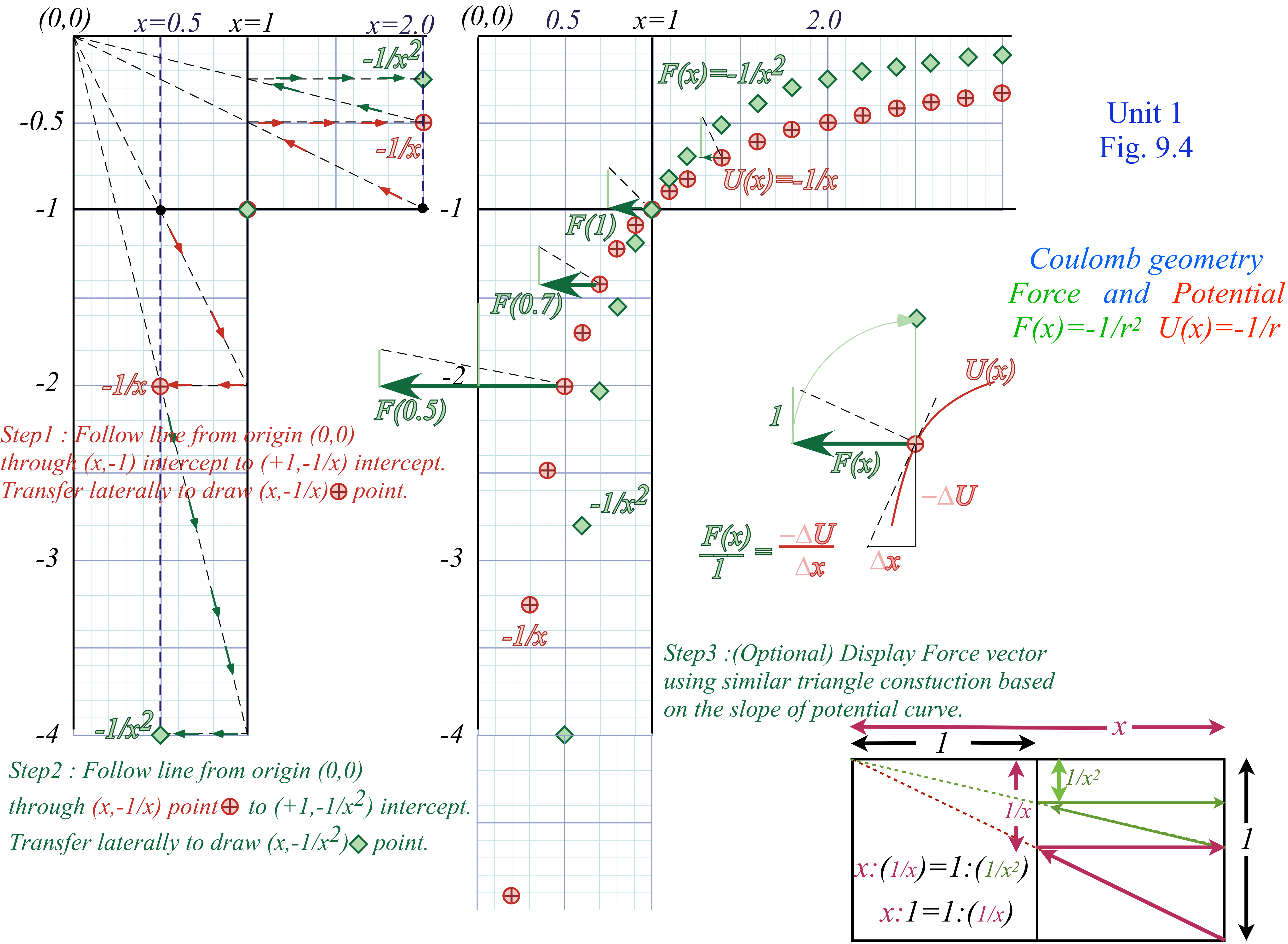
Coulomb geometry
Force and Potential
$F(x)=-1/r^2$ $U(x)=-1/r$



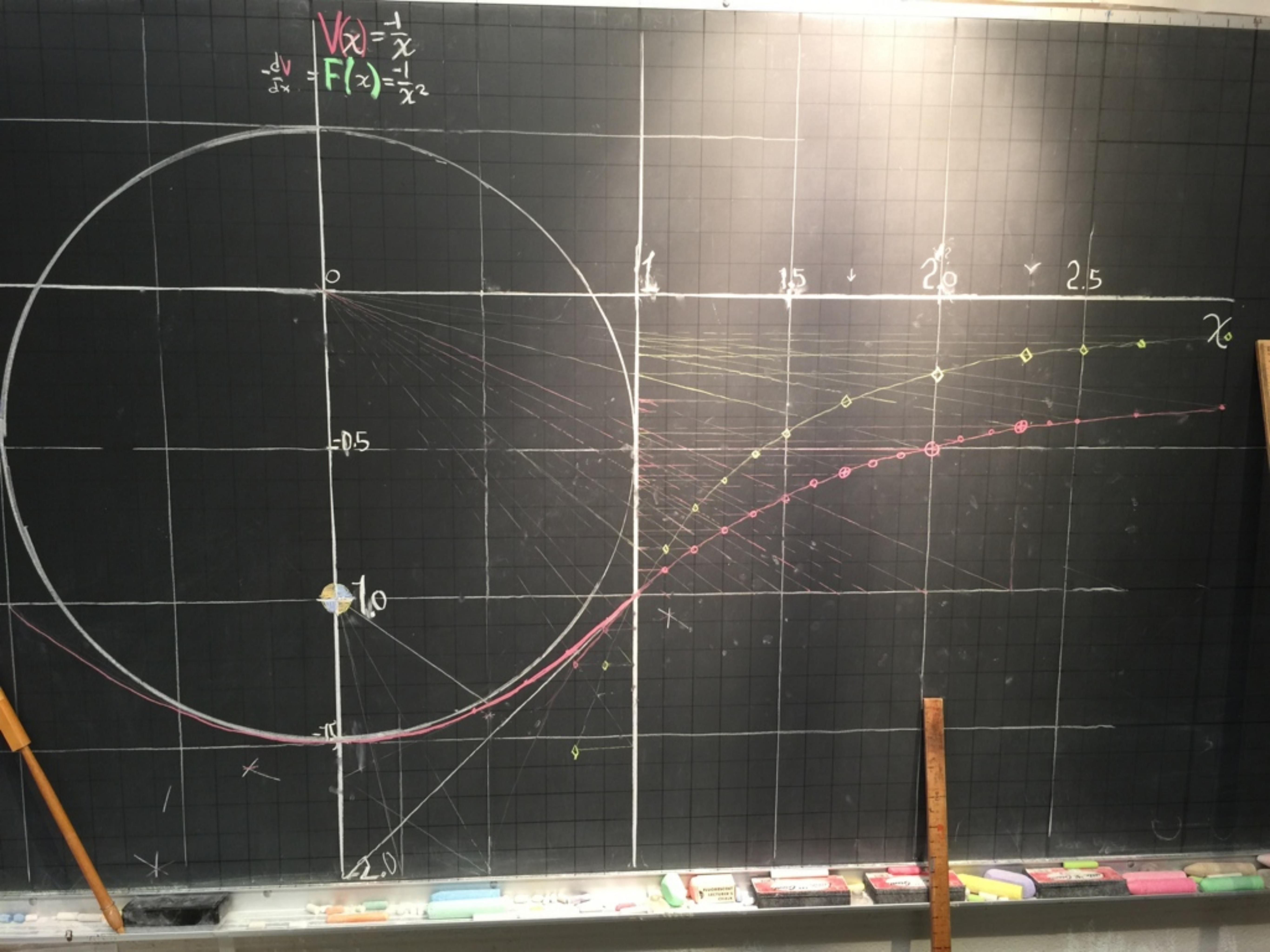
Step1 : Follow line from origin (0,0) through (x,-1) intercept to (+1,-1/x) intercept. Transfer laterally to draw (x,-1/x)⊕ point.

Step2 : Follow line from origin (0,0) through (x,-1/x) point⊕ to $(+1,-1/x^2)$ intercept. Transfer laterally to draw $(x,-1/x^2)$◇ point.




(0,0)
x=0.5
x=1
x=2.0
-1/x²
-0.5
-1/x
-1
-2
-1/x
-3
-4
-1/x²
(0,0)
0.5
x=1
2.0
F(x)=-1/x²
U(x)=-1/x
F(1)
F(0.7)
F(0.5)
-1/x²
-1/x
Coulomb geometry
Force and Potential
F(x)=-1/r² U(x)=-1/r
U(x)
1
F(x)
−ΔU
F(x)/1 = −ΔU/Δx
Δx
Step1 : Follow line from origin (0,0) through (x,-1) intercept to (+1,-1/x) intercept. Transfer laterally to draw (x,-1/x)⊕ point.
Step2 : Follow line from origin (0,0) through (x,-1/x) point⊕ to (+1,-1/x²) intercept. Transfer laterally to draw (x,-1/x²)◇ point.
Step3 :(Optional) Display Force vector using similar triangle constuction based on the slope of potential curve.
x
1
1/x²
1/x
1
x:(1/x)=1:(1/x²)
x:1=1:(1/x)

Unit 1
Fig. 9.4



V(x) = -1/x
-dV/dx = F(x) = -1/x²
0
1
1.5
2.0
2.5
x
-0.5
-1.0
-1.5
-2.0

Geometry of common power-law potentials

Geometric (Power) series

"Zig-Zag" exponential geometry

Projective or perspective geometry

Parabolic geometry of harmonic oscillator $kr^2/2$ potential and $-kr^1$ force fields

Coulomb geometry of $-1/r$-potential and $-1/r^2$-force fields

→ *Compare mks units of Coulomb Electrostatic vs. Gravity*

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong \boxed{?.?\cdot 10^{?}} \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.) !!!!

~9E9~10^{10}

$$F^{elec.}(r) = \pm\frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000\,\frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

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More precise value for electrostatic constant : $1/4\pi\varepsilon_0 = 8.987{,}551 \cdot 10^9 Nm^2/C^2$ $\sim 9 \cdot 10^9 \sim 10^{10}$

quantum of charge: $|e| = 1.6022 \cdot 10^{-19}$ Coulomb

↑

Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)

...but 1 Ampere = 1 Coulomb/sec.

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.) !!!!

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Attractive (+)(-) or (-)(+)

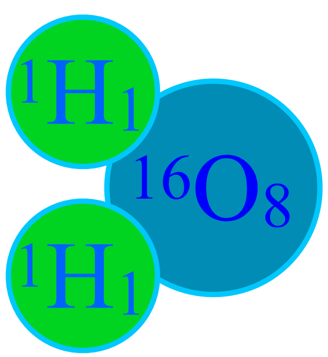
...but 1 Ampere = 1 Coulomb/sec.

"Fingertip Physics" of Ch. 8 notes that 1 $(cm)^3$ =1gm of water (1/18 Mole) has (1/18) $6 \cdot 10^{23}$ molecules

Avogodro's Number

$\sim 0.3 \cdot 10^{23}$

H_2O Molecular weight~18



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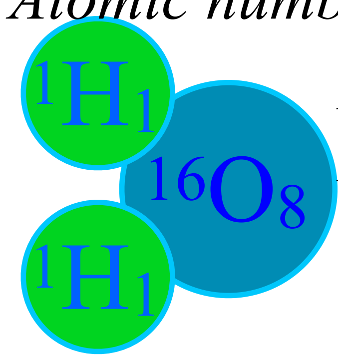
"Fingertip Physics" of Ch. 9 notes that 1 $(cm)^3$ =1gm of water (1/18 Mole) has (1/18) $6\cdot 10^{23}$ molecules or ~ $3\cdot 10^{23}$ electrons and ~ $3\cdot 10^{23}$ protrons.

~$0.3\cdot 10^{23}$

H_2O Molecular weight~18

Atomic number = 10



10 electrons
10 protons

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

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$\sim 0.3\cdot 10^{23}$

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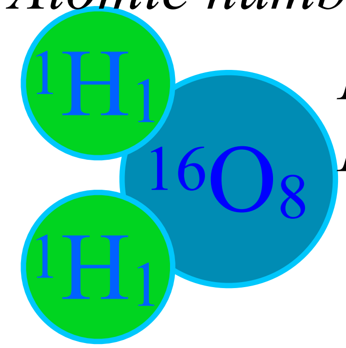


10 electrons *That is ~ $-3\cdot 10^{23}\, 1.6022\cdot 10^{-19}$ Coulomb or about $-0.5\cdot 10^{+5}$ C or $-$ 50,000 Coulomb*

10 protons *plus ~ $+3\cdot 10^{23}\, 1.6022\cdot 10^{-19}$ Coulomb or about $+0.5\cdot 10^{+5}$ C or +50,000 Coulomb*

Equals zero total charge

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.) !!!!

~9E9~10^{10}

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

More precise value for electrostatic constant : $1/4\pi\varepsilon_0 = 8.987{,}551 \cdot 10^9 Nm^2/C^2$ $\sim 9 \cdot 10^9 \sim 10^{10}$

quantum of charge: $|e| = 1.6022 \cdot 10^{-19}$ Coulomb

↑

Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)
vs
Always Attractive (so far)

↓

↕ COMPARE! ↕

BIG
vs
small

2. Gravitational force between m(kilograms) and M(kg.)

$$F^{grav.}(r) = -G\frac{mM}{r^2} \quad where: G = \boxed{?.? \cdot 10^{?}} \ \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.) !!!!

~9E9~10^{10}

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

More precise value for electrostatic constant : $1/4\pi\varepsilon_0 = 8.987{,}551 \cdot 10^9 Nm^2/C^2$ ~$9\cdot10^9$~10^{10}

quantum of charge: $|e| = 1.6022 \cdot 10^{-19}$ Coulomb

↑

Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)
vs
Always Attractive (so far)

↓

↕ COMPARE! ↕

BIG
vs
small

2. Gravitational force between m(kilograms) and M(kg.) !!!!

~ $^2/_3 10^{-10}$~10^{-10}

$$F^{grav.}(r) = -G\frac{mM}{r^2} \quad where: G = 0.000{,}000{,}000{,}067 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

More precise value for gravitational constant : $G = 6.67384(80) \cdot 10^{-11} Nm^2/C^2$ ~$(2/3)10^{-10}$

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

quantum of charge: $|e|=1.6022\cdot 10^{-19}$ Coulomb

↑

Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)

Discussion of repulsive force and PE in Ch. 9...

1(a). Electrostatic potential energy between q(Coulombs) and Q(C.)

$\sim 9E9 \sim 10^{10}$!!!!

$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Joule}{per\ square\ Coulomb}$$

Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

↑

Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)

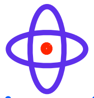
quantum of charge: $|e| = 1.6022 \cdot 10^{-19}$ *Coulomb*

Discussion of repulsive force and PE in Ch. 9...

1(a). Electrostatic potential energy between q(Coulombs) and Q(C.)

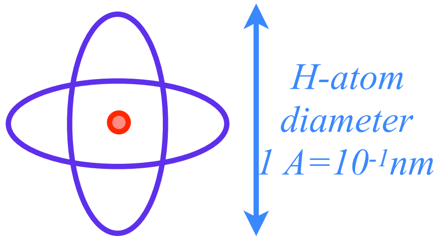
~9E9~10^{10} *!!!!*

$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Joule}{per\ square\ Coulomb}$$



Nuclear size ~ 10^{-15} *m = 1 femtometer =1fm*

Atomic size ~ 1 Angstrom = 10^{-10} *m*



Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0} \frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

quantum of charge: $|e|=1.6022 \cdot 10^{-19}$ Coulomb

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Repulsive (+)(+) or (-)(-)
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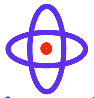
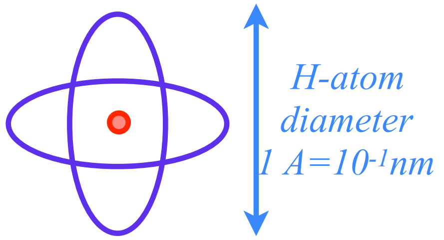
Nuclear size ~ 10^{-15} m = 1 femtometer =1fm



Atomic size ~ 1 Angstrom = 10^{-10} m

Big molecule ~ 10 Angstrom = 10^{-9} m = 1nanometer=1nm



Compare mks units for Coulomb fields

1. Electrostatic force between q(Coulombs) and Q(C.)

$$F^{elec.}(r) = \pm \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r^2} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Newtons \cdot meter \cdot square}{per\ square\ Coulomb}$$

↑

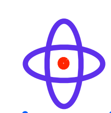
Repulsive (+)(+) or (-)(-)
Attractive (+)(-) or (-)(+)

quantum of charge: $|e| = 1.6022 \cdot 10^{-19}$ *Coulomb*

Discussion of repulsive force and PE in Ch. 9...

1(a). Electrostatic potential energy between q(Coulombs) and Q(C.)

$$U(r) = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r} \quad where: \frac{1}{4\pi\varepsilon_0} \cong 9{,}000{,}000{,}000 \frac{Joule}{per\ square\ Coulomb}$$

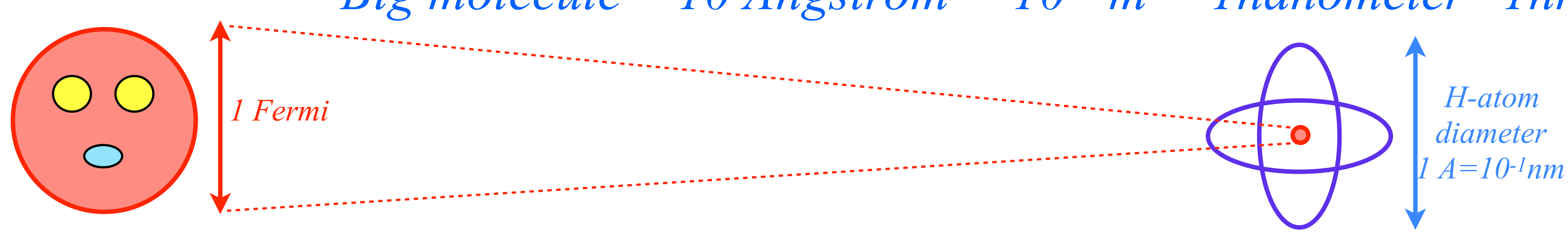


Nuclear size ~ 10^{-15} *m = 1 femtometer =1fm*

Atomic size ~ 1 Angstrom = 10^{-10} *m*

Big molecule ~ 10 Angstrom = 10^{-9} *m = 1nanometer=1nm*

also:1fm = 10^{-13} *cm =1Fermi*
=1Fm



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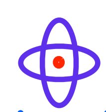

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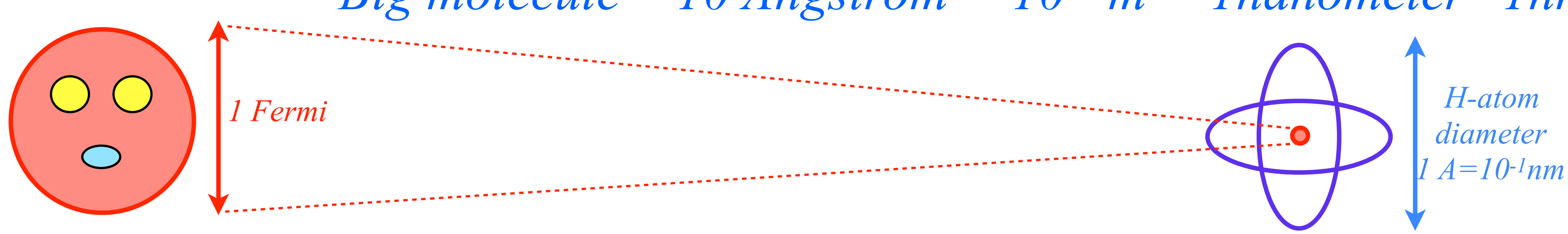


nuclear radii are 100,000 to 1,000,000 times smaller than atomic/chemical radii

...so nuclear qQ/r energy 100,000 to 1,000,000 times **larger** than that of atomic/chemical...

Geometry of idealized "Sophomore-physics Earth"

Coulomb field *<u>outside</u>*   *Isotropic Harmonic Oscillator (IHO) field* *<u>inside</u>*

Contact-geometry of potential curve(s)

"Crushed-Earth" models: 3 key energy "steps" and 4 key energy "levels"

Earth matter vs nuclear matter:

*Introducing the "neutron starlet" and "***Black-Hole-Earth***"*

Coulomb force vanishes inside-spherical shell (Gauss-law)

Unit 1
Fig. 9.6

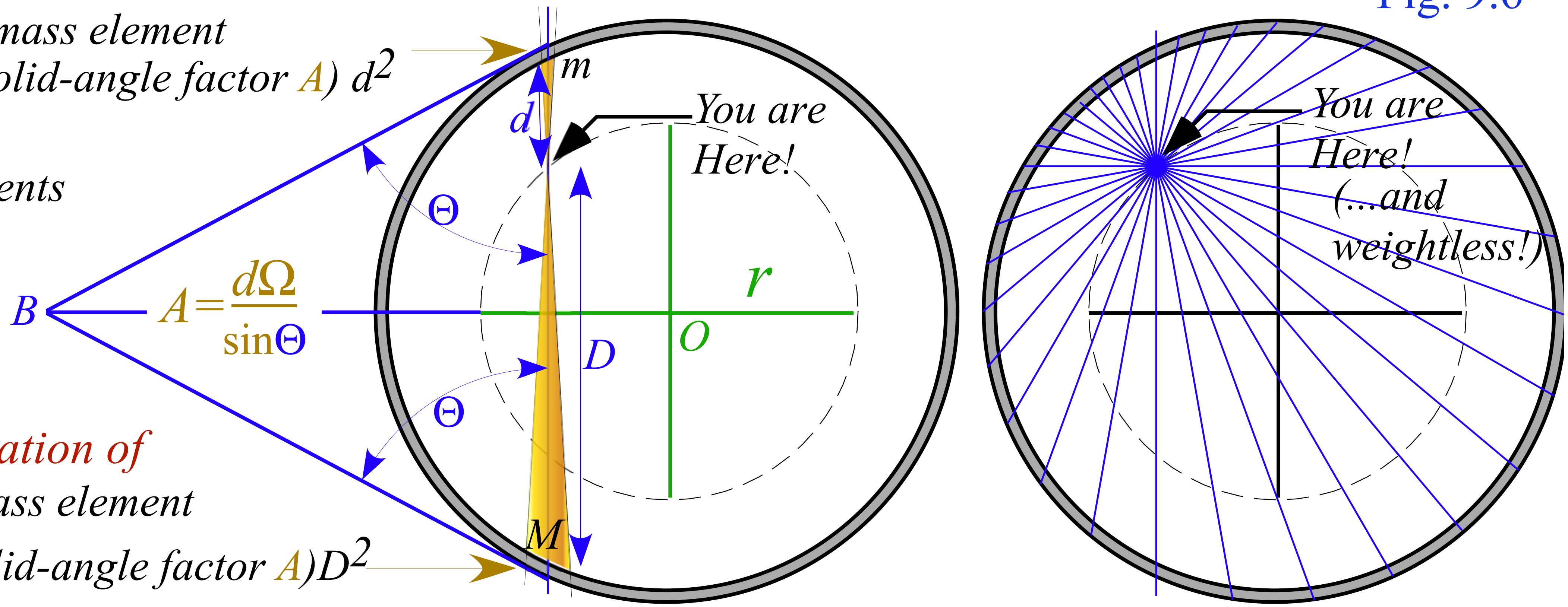
Shell mass element
m =(solid-angle factor A) d^2

Gravity at r
due to shell mass elements

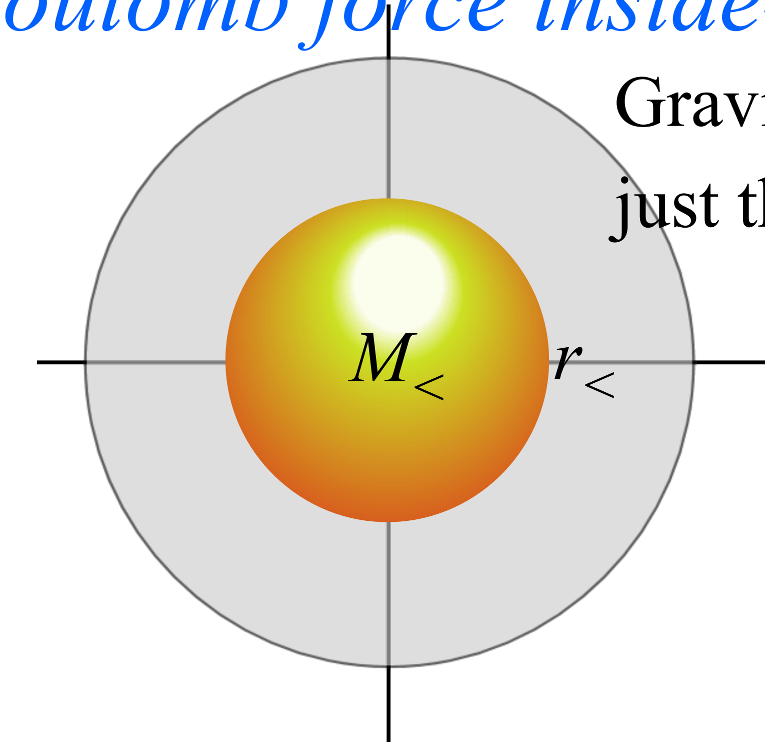
$$\frac{G\,M}{D^2} - \frac{G\,m}{d^2} =$$

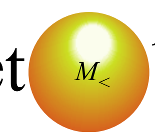
$$\left(\frac{D^2}{D^2} - \frac{d^2}{d^2}\right)A = 0$$

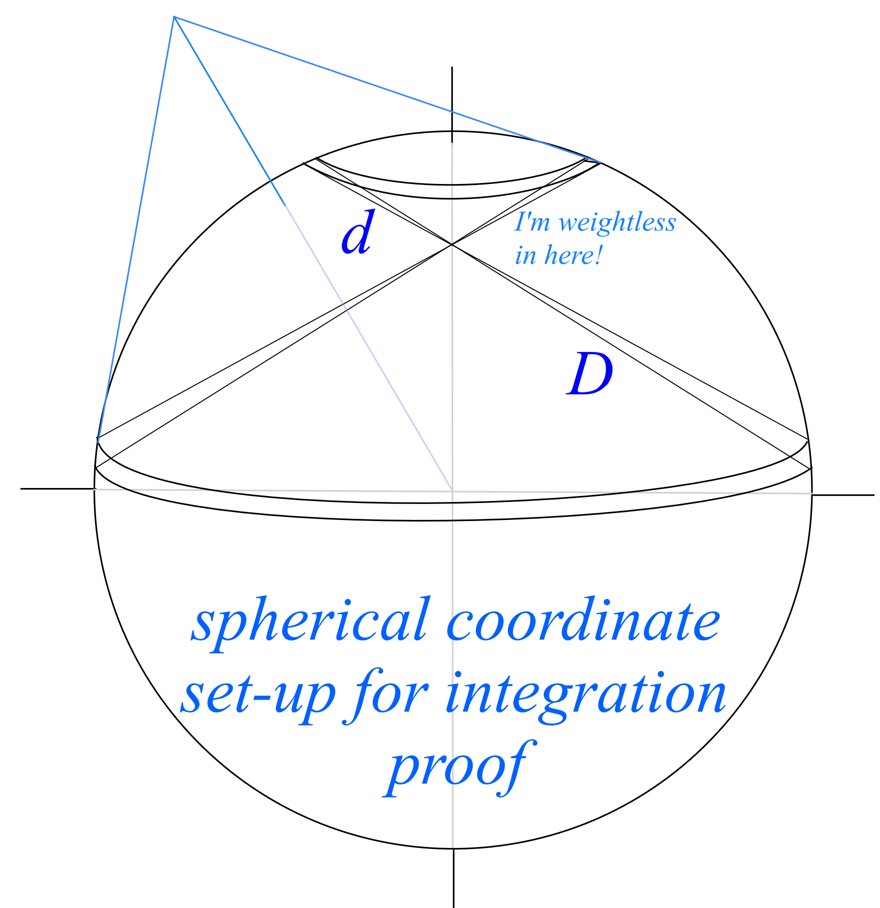
Cancellation of
Shell mass element
M =(solid-angle factor A)D^2



Coulomb force inside-spherical body due to stuff below you, only.



Gravitational force at $r_<$ is just that of planet  below $r_<$



Coulomb force vanishes inside-spherical shell *(Gauss-law)*

Unit 1
Fig. 9.6

Gravity at r
due to shell mass elements

$$\frac{G\,M}{D^2} - \frac{G\,m}{d^2} = $$

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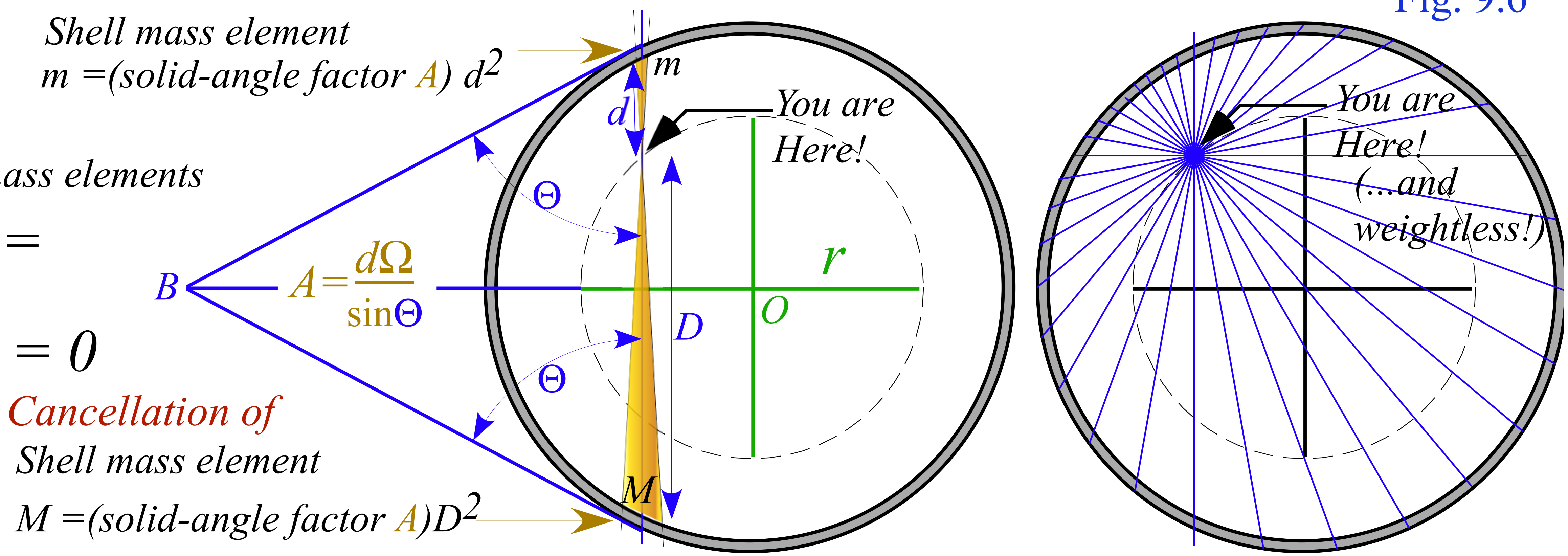
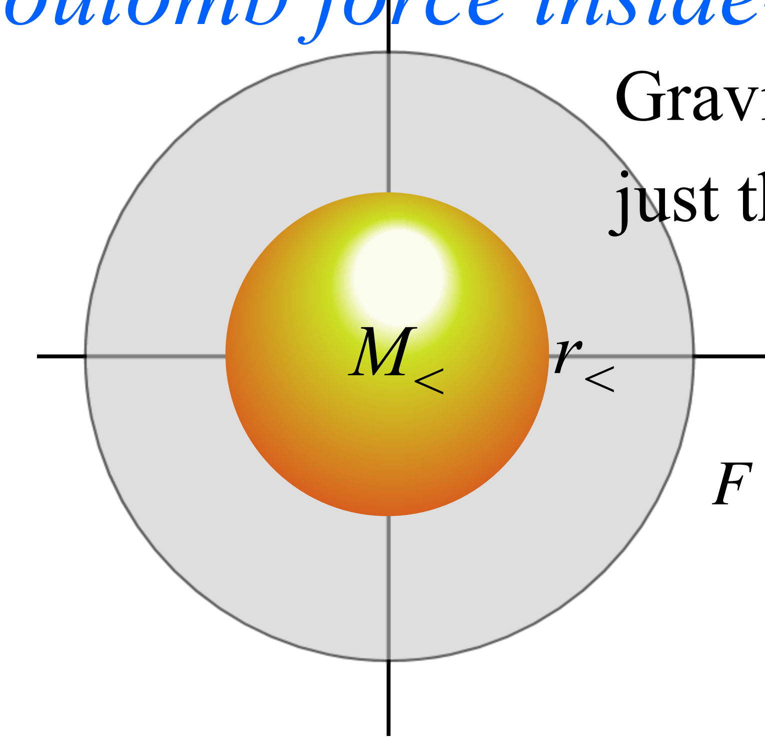


Coulomb force inside-spherical body due to stuff <u>below</u> you, <u>only</u>.



Gravitational force at $r_<$ is
just that of planet below $r_<$

Note:
Hooke's (linear) force law
for $r_<$ inside uniform body

$$F^{inside}(r_<) = G\frac{mM_<}{r_<^2} = Gm\frac{4\pi}{3}\frac{M_<}{\frac{4\pi}{3}r_<^3}r_< = Gm\frac{4\pi}{3}\rho_\oplus r_< = mg\frac{r_<}{R_\oplus} \equiv mg\cdot x$$

Coulomb force vanishes inside-spherical shell *(Gauss-law)*

Unit 1
Fig. 9.6

Shell mass element
m =(solid-angle factor A) d^2

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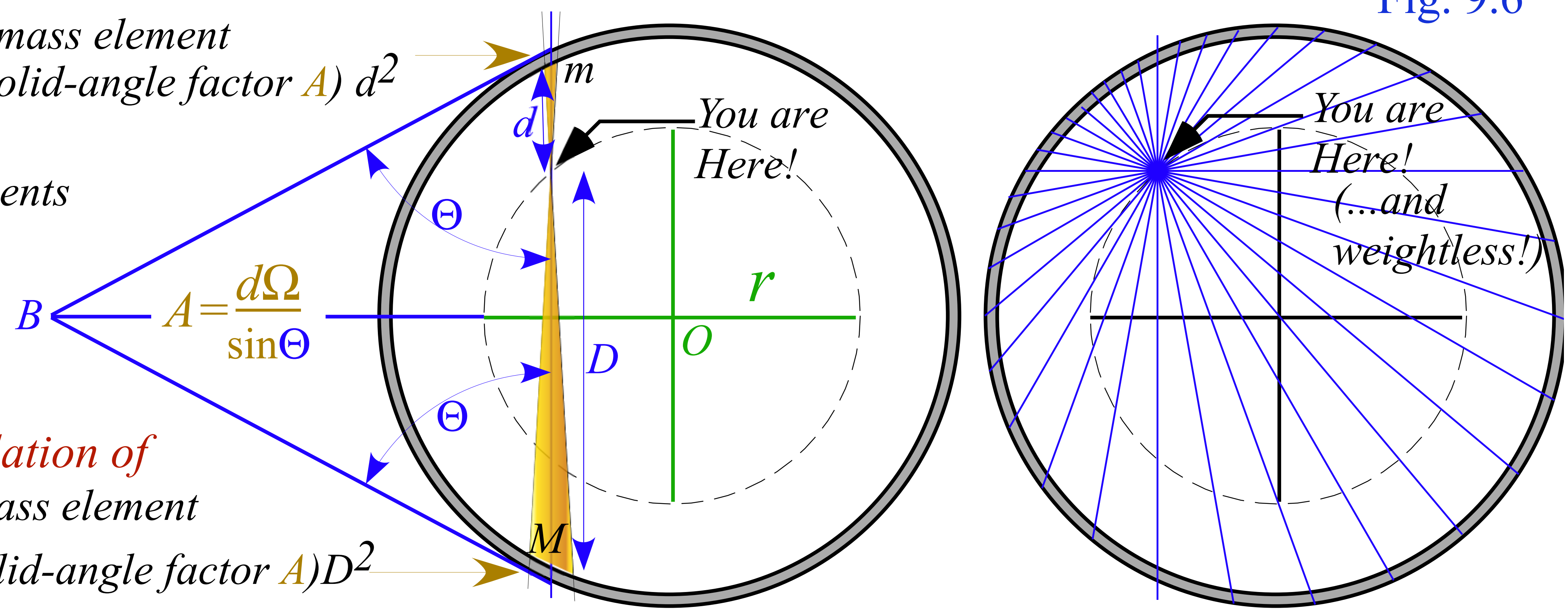
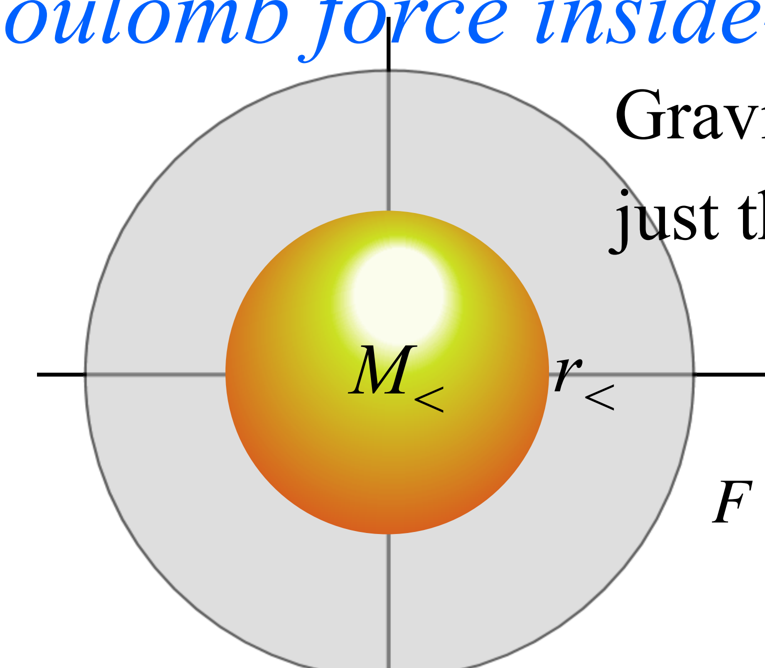


Coulomb force inside-spherical body due to stuff below you, only.



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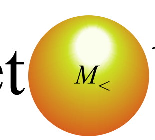
just that of planet  below $r_<$

Note:
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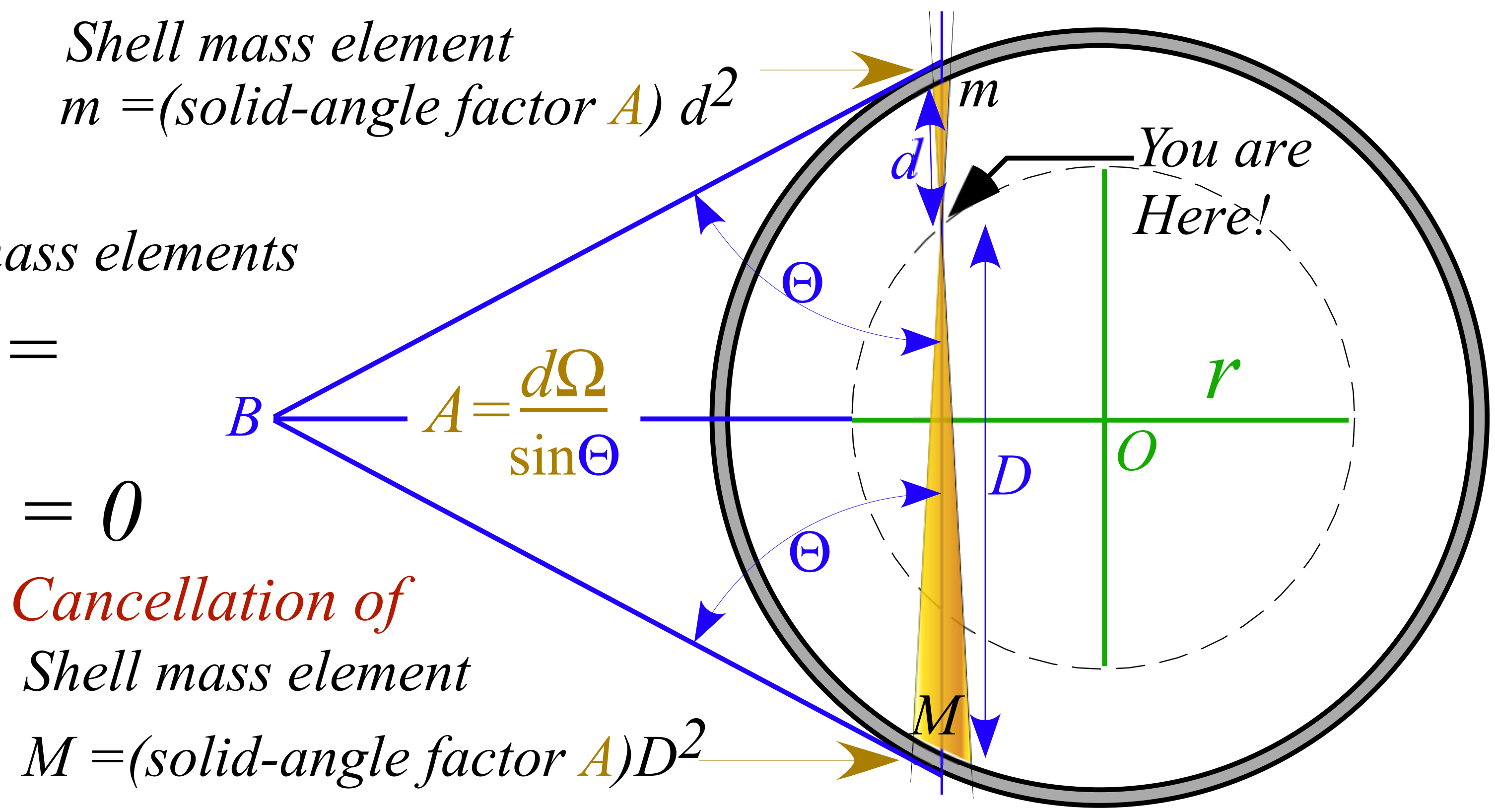
Earth surface gravity acceleration: $g = G\frac{M_\oplus}{R_\oplus^2} = G\frac{M_\oplus}{R_\oplus^3}R_\oplus = G\frac{4\pi}{3}\frac{M_\oplus}{\frac{4\pi}{3}R_\oplus^3}R_\oplus = G\frac{4\pi}{3}\rho_\oplus R_\oplus = 9.8m/s$

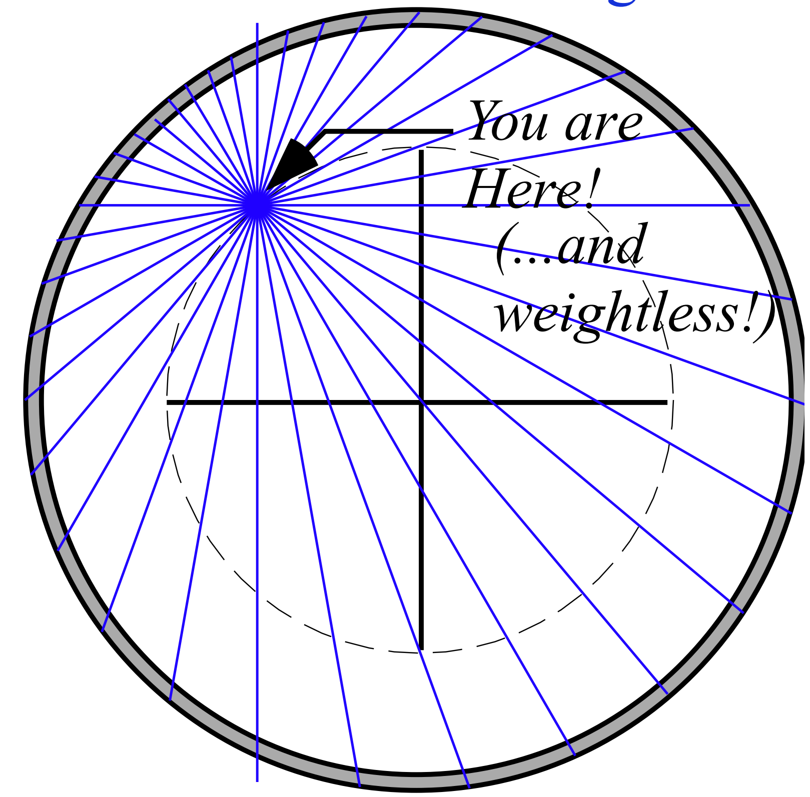
$G=6.67384(80)\cdot 10^{-11}Nm^2/C^2 \sim (2/3)10^{-10}$

Coulomb force vanishes inside-spherical shell (Gauss-law)

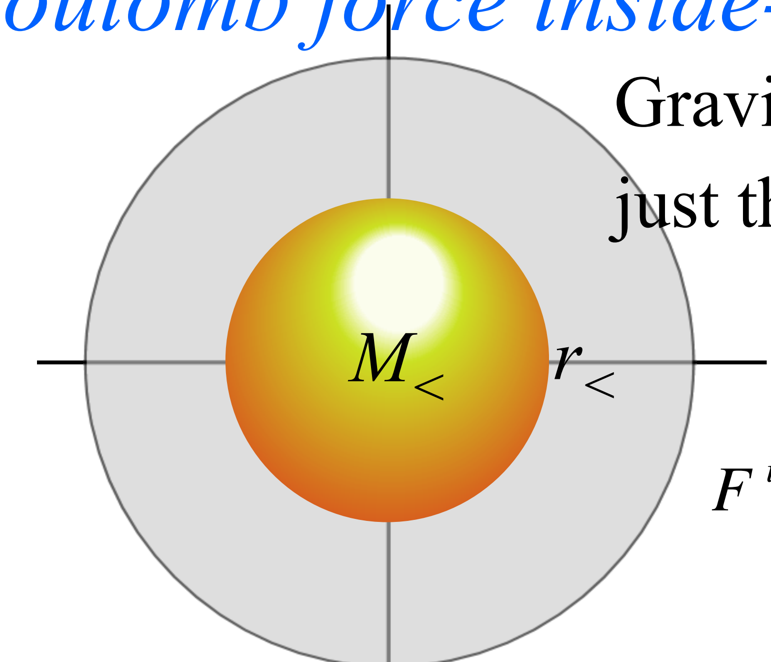
Gravity at r
due to shell mass elements

$$\frac{GM}{D^2} - \frac{Gm}{d^2} = \left(\frac{D^2}{D^2} - \frac{d^2}{d^2}\right)A = 0$$





Coulomb force inside-spherical body due to stuff below you, only.



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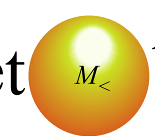
just that of planet  below $r_<$

Note:
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Earth surface gravity acceleration: $g = G\frac{M_\oplus}{R_\oplus^2} = G\frac{M_\oplus}{R_\oplus^3}R_\oplus = G\frac{4\pi}{3}\frac{M_\oplus}{\frac{4\pi}{3}R_\oplus^3}R_\oplus = G\frac{4\pi}{3}\rho_\oplus R_\oplus = 9.8m/s$

G=6.67384(80)·10^{-11}Nm^2/C^2 ~(2/3)10^{-10}

Earth radius : $R_\oplus = 6.371\cdot 10^6\, m \simeq 6.4\cdot 10^6\, m$

Earth mass : $M_\oplus = 5.9722 \times 10^{24}\, kg. \simeq 6.0\cdot 10^{24}\, kg.$

Solar radius : $R_\odot = 6.955 \times 10^8\, m. \simeq 7.0\cdot 10^8\, m.$

Solar mass : $M_\odot = 1.9889 \times 10^{30}\, kg. \simeq 2.0\cdot 10^{30}\, kg.$

Geometry of idealized "Sophomore-physics Earth"

Coulomb field *<u>outside</u>* *Isotropic Harmonic Oscillator (IHO) field* *<u>inside</u>*

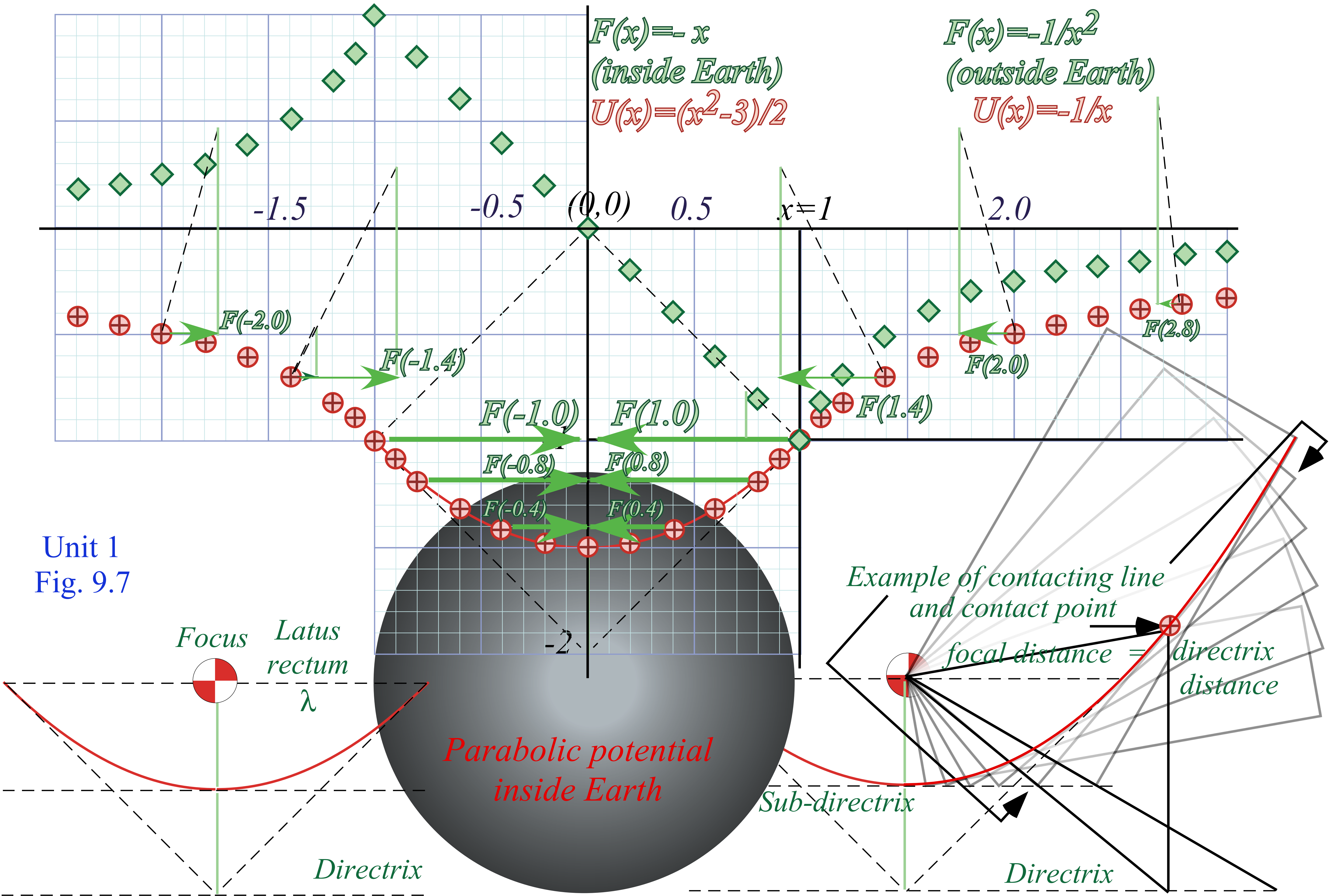
→ *Contact-geometry of potential curve(s)*

"Crushed-Earth" models: 3 key energy "steps" and 4 key energy "levels"

Earth matter vs nuclear matter:

*Introducing the "neutron starlet" and "***Black-Hole-Earth***"*

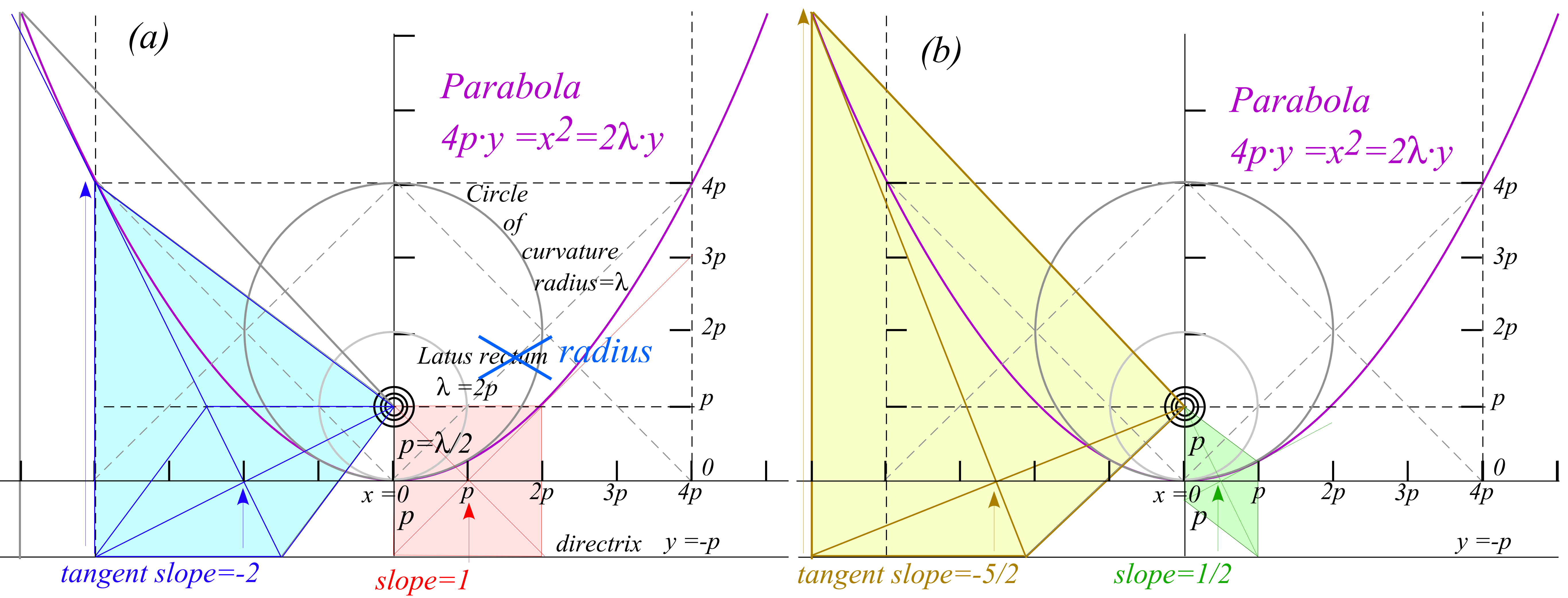
The ideal "Sophomore-Physics-Earth" model of geo-gravity



Unit 1
Fig. 9.7

...conventional parabolic geometry...carried to extremes...

(From p.18)



Unit 1
Fig. 9.4

Geometry of idealized "Sophomore-physics Earth"

Coulomb field *<u>outside</u>* *Isotropic Harmonic Oscillator (IHO) field* *<u>inside</u>*

Contact-geometry of potential curve(s)

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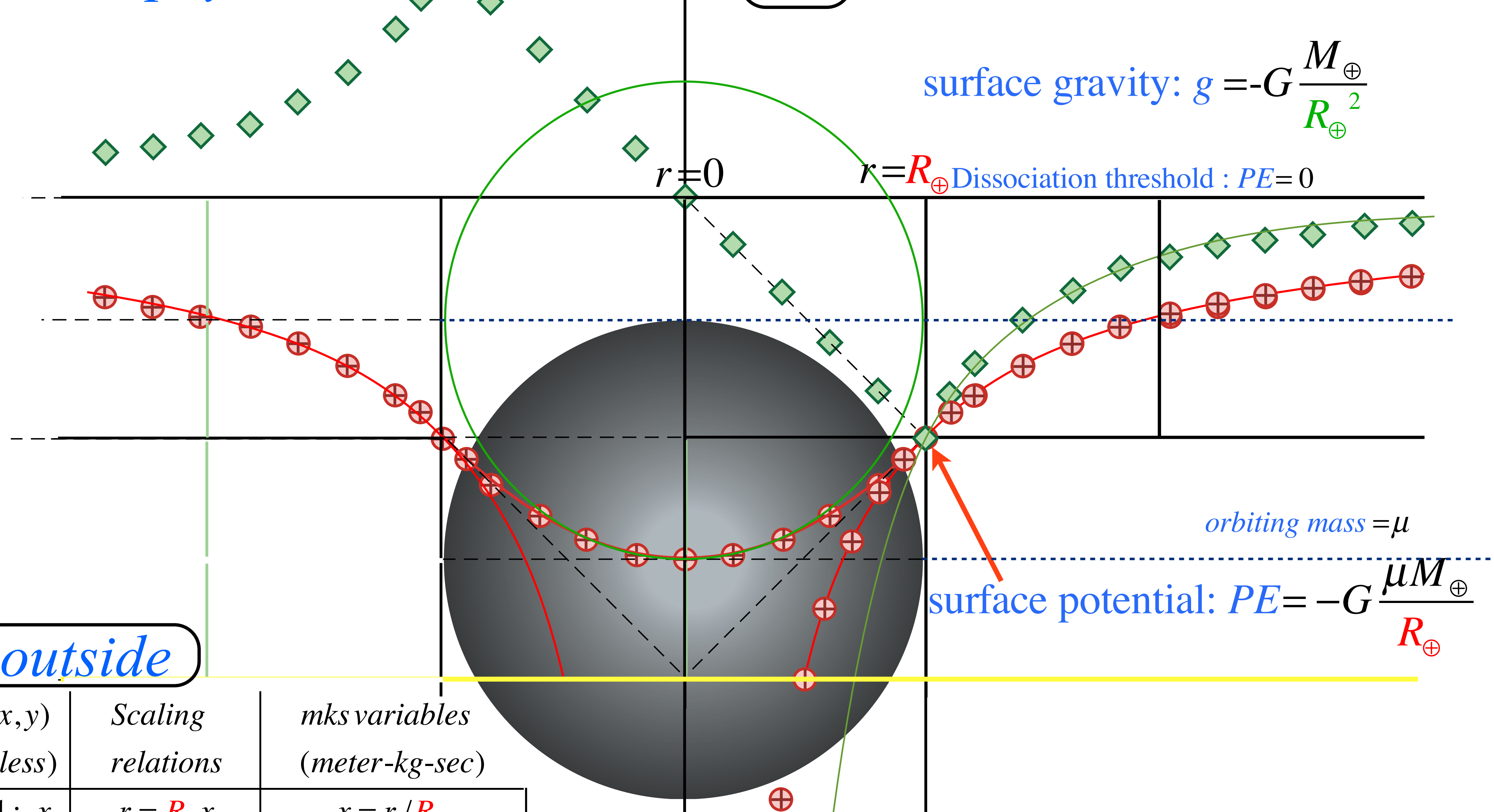
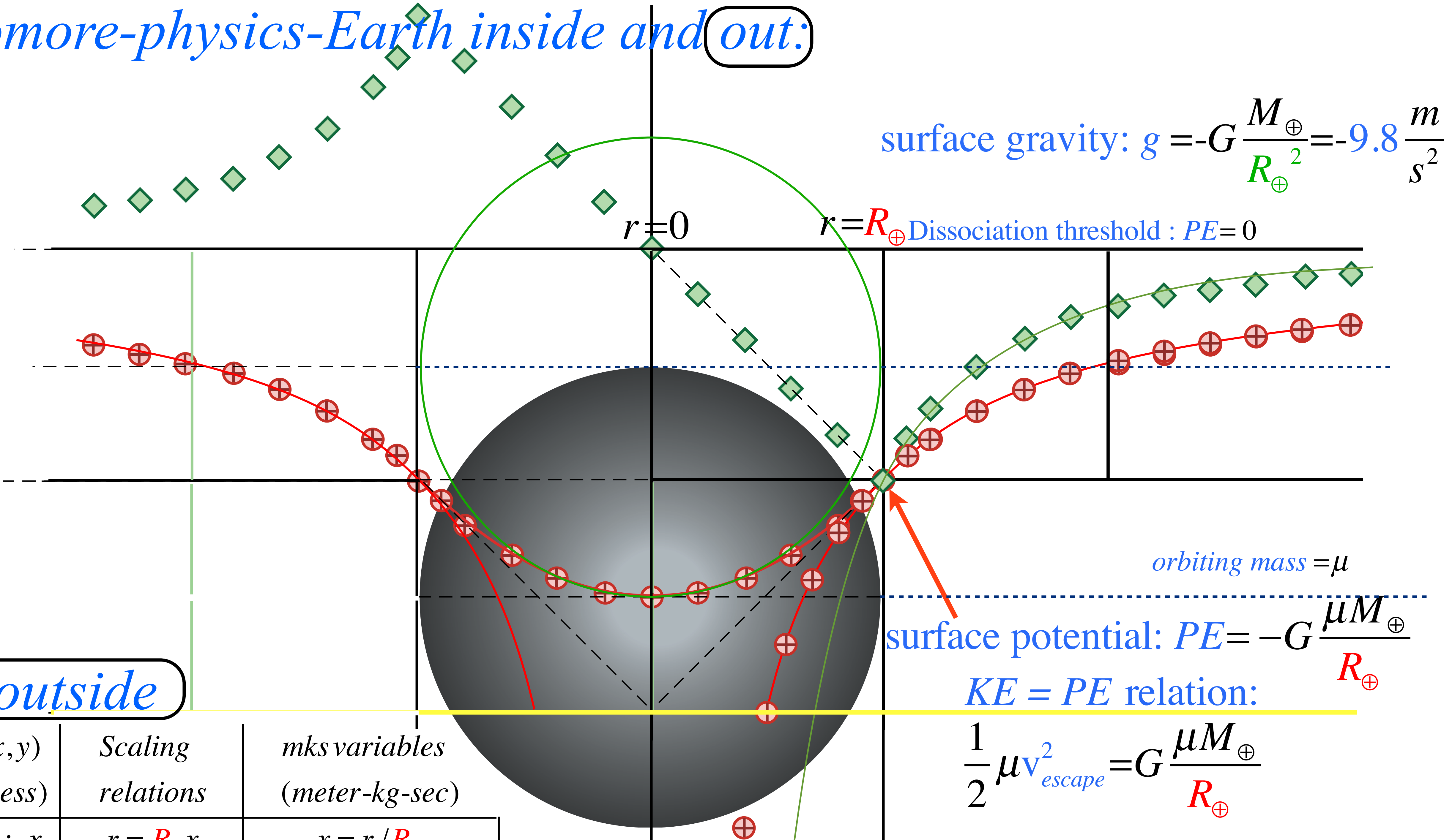
Sophomore-physics-Earth inside and out:



Geometric (x,y) (*Dimensionless*)	*Scaling relations*	*mks variables* (*meter-kg-sec*)
space coord.: x	$r = R_\oplus x$	$x = r / R_\oplus$
PE for $\lvert x \rvert \geq 1$: $y^{PE} = \frac{-1}{x}$	$PE^{mks}(r) = \frac{GM\mu}{R_\oplus} y^{PE}$	$PE^{mks}(r) = -\frac{GM\mu}{r} = -\frac{GM\mu}{R_\oplus}\frac{1}{x}$

Sophomore-physics-Earth inside and out:



Geometric (x,y) (*Dimensionless*)	*Scaling relations*	*mks variables* (*meter-kg-sec*)
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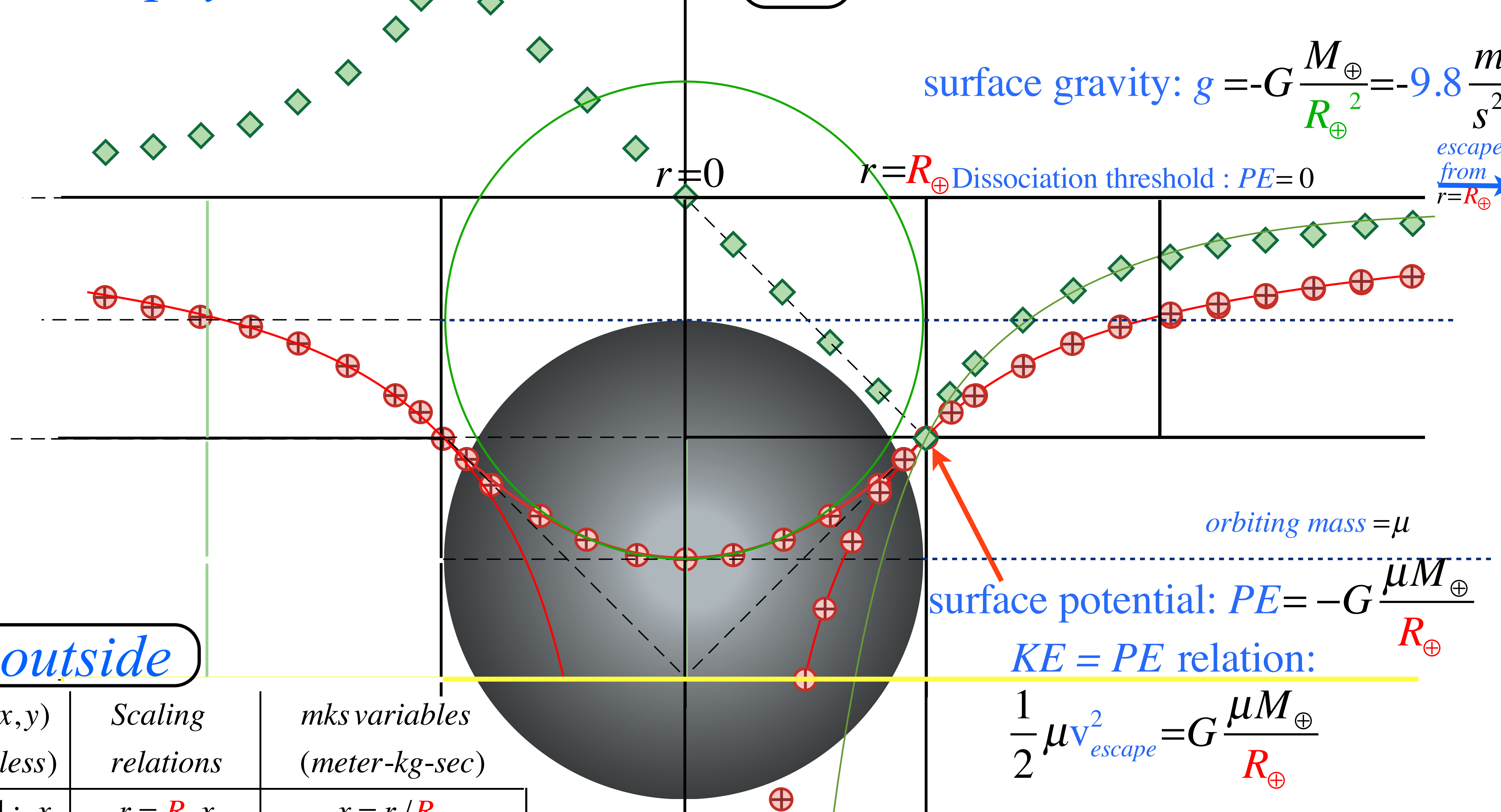

surface gravity: $g = -G\dfrac{M_\oplus}{R_\oplus^{\;2}} = -9.8\dfrac{m}{s^2}$

surface potential: $PE = -G\dfrac{\mu M_\oplus}{R_\oplus}$

$KE = PE$ relation:

$$\frac{1}{2}\mu v_{escape}^2 = G\frac{\mu M_\oplus}{R_\oplus}$$

$R_\oplus$-escape-velocity

$$v_{escape} = \sqrt{2G\frac{M_\oplus}{R_\oplus}}$$

Geometric (x,y) (Dimensionless)	*Scaling relations*	*mks variables (meter-kg-sec)*
space coord.: x	$r = R_\oplus x$	$x = r/R_\oplus$
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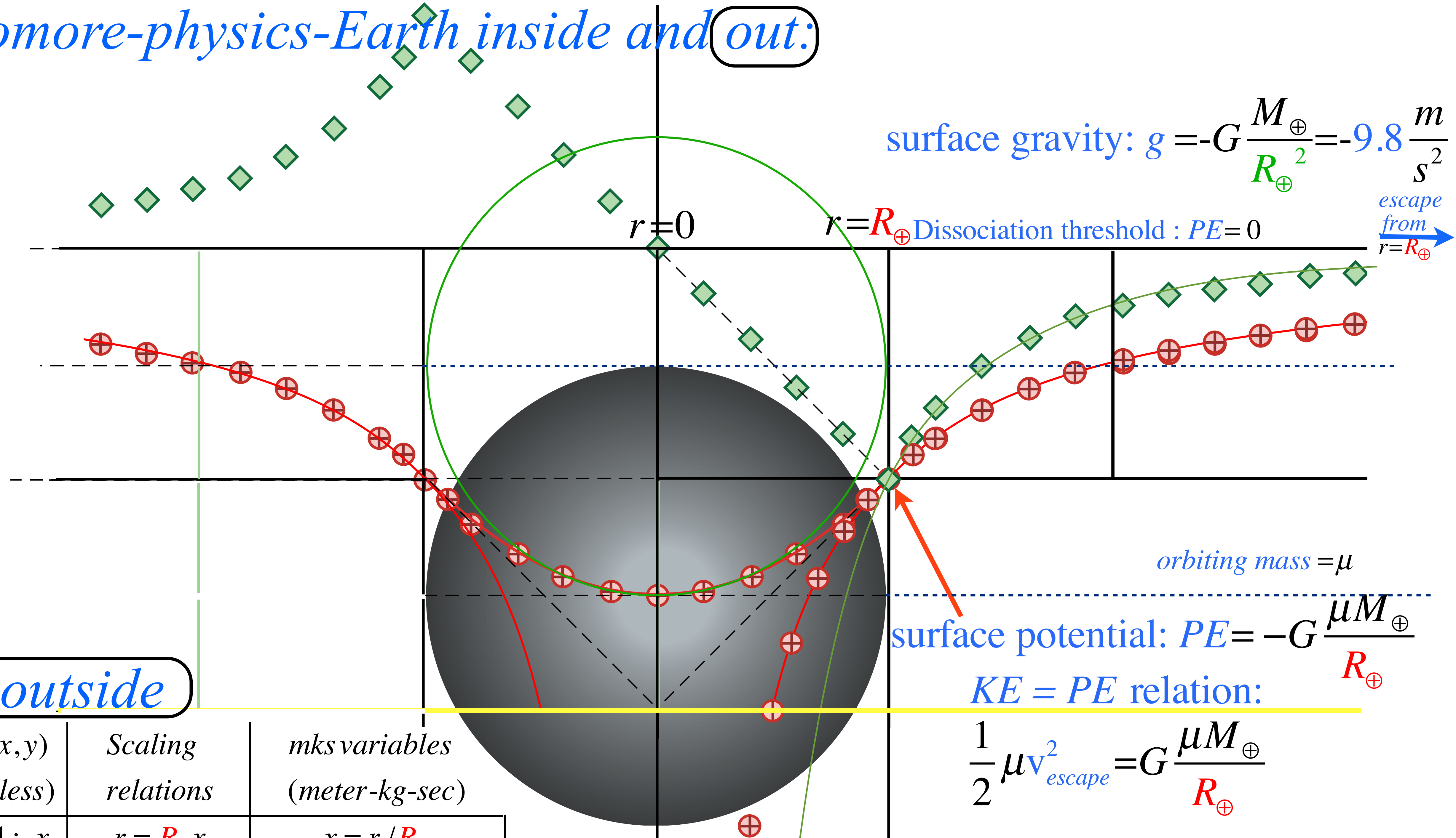
Sophomore-physics-Earth inside and out:



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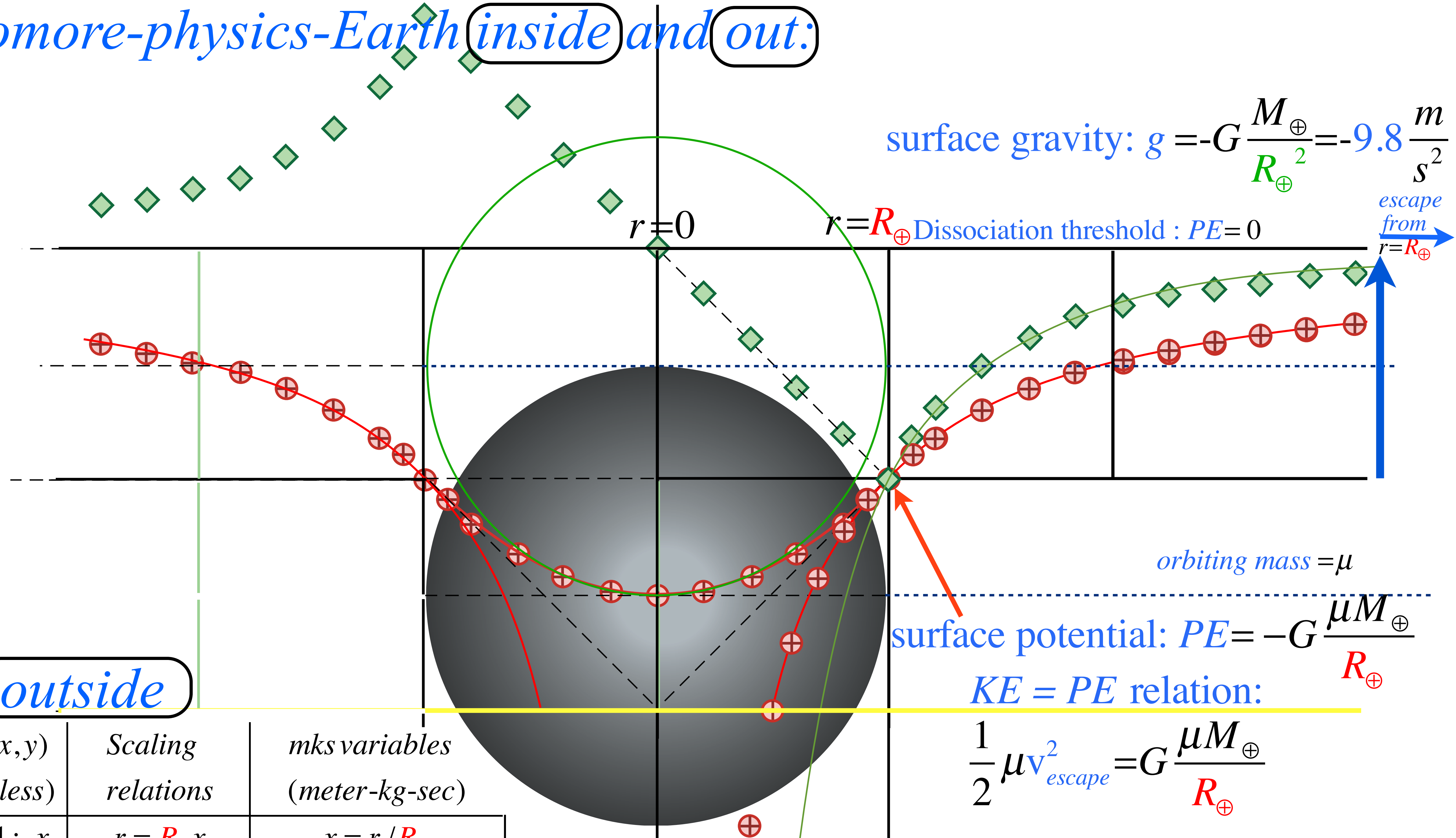
Force for $\lvert x\rvert \geq 1$: $y^{Force} = \dfrac{-1}{x^2}$	$F^{mks}(r) = \dfrac{GM\mu}{R_\oplus^2} y^{Force}$	$F^{mks}(r) = -\dfrac{GM\mu}{r^2} = -\dfrac{GM\mu}{R_\oplus^2}\dfrac{1}{x^2}$

Sophomore-physics-Earth inside and out:



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Geometric (x,y) (Dimensionless)	Scaling relations	mks variables (meter-kg-sec)		
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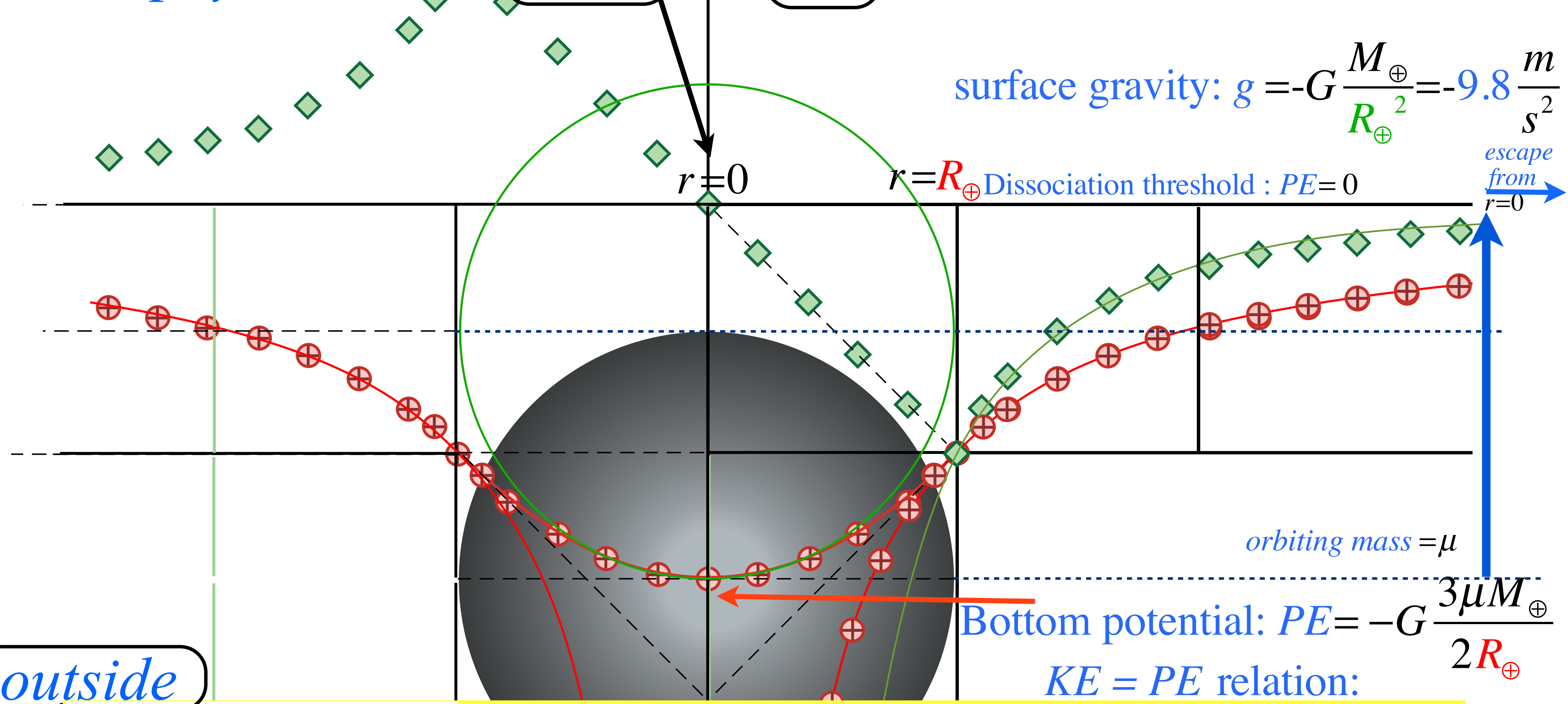
$Force$ for $\lvert x \rvert \geq 1$: $y^{Force} = \frac{-1}{x^2}$	$F^{mks}(r) = \frac{GM\mu}{R_\oplus^2} y^{Force}$	$F^{mks}(r) = -\frac{GM\mu}{r^2} = -\frac{GM\mu}{R_\oplus^2}\frac{1}{x^2}$	$Force$ for $\lvert x \rvert < 1$: $y^{Force} = -x$	$F^{mks}(r) = -\frac{GM\mu}{R_\oplus^3} r$

$R_\oplus$-escape-velocity

$$v_{escape} = \sqrt{2G\frac{M_\oplus}{R_\oplus}}$$

11.1km/sec

Sophomore-physics-Earth inside and out:



Geometric (x,y) (Dimensionless)	Scaling relations	mks variables (meter-kg-sec)		
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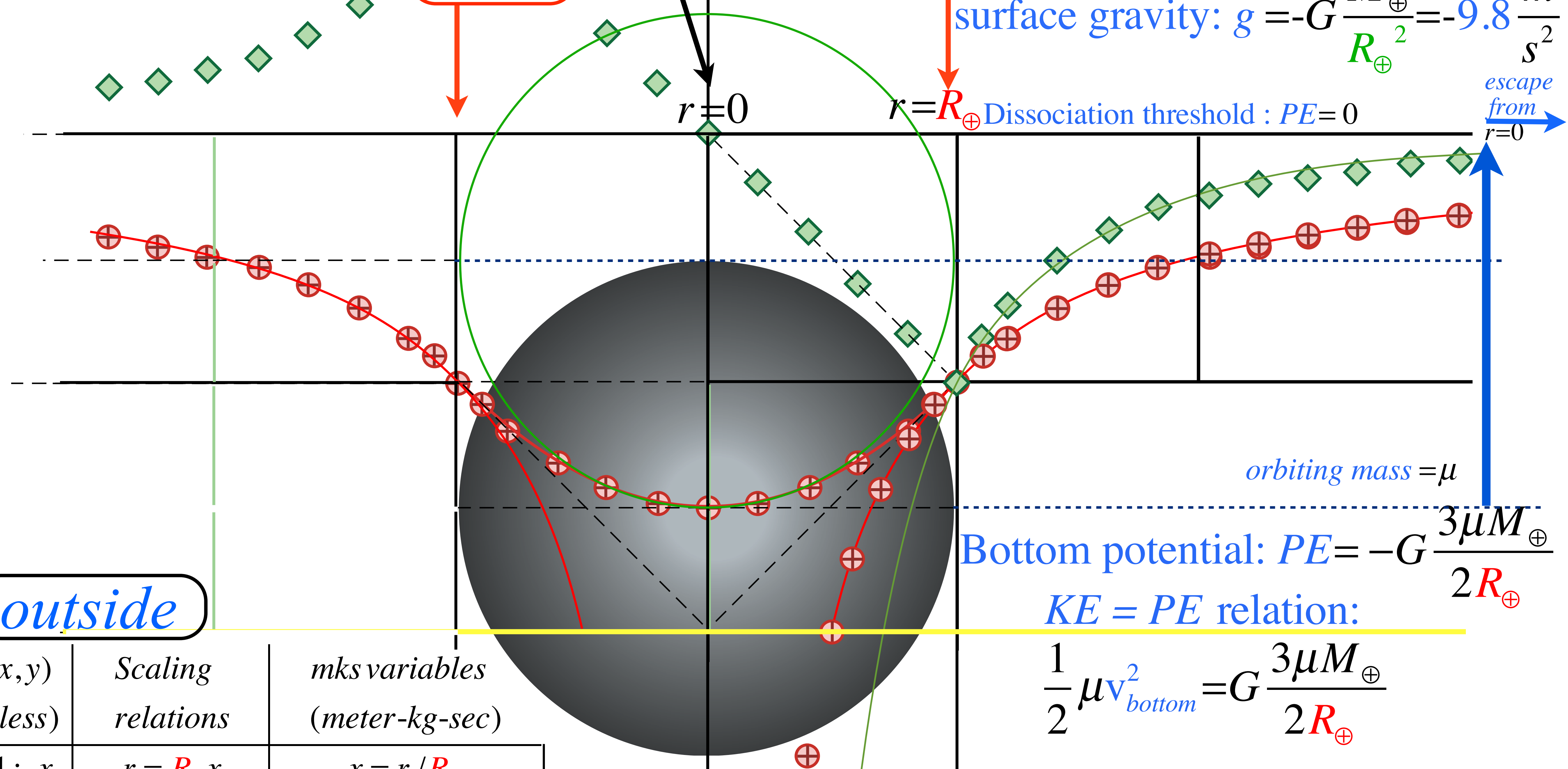
$(r=0)$-escape-velocity

$$v_{bottom} = \sqrt{3G\frac{M_\oplus}{R_\oplus}}$$

13.7km/sec

Sophomore-physics-Earth inside and out:
...and surface orbit at $r=R_\oplus$



surface gravity: $g = -G\dfrac{M_\oplus}{R_\oplus{}^2} = -9.8\,\dfrac{m}{s^2}$

Bottom potential: $PE = -G\dfrac{3\mu M_\oplus}{2R_\oplus}$

$KE = PE$ relation:

$$\frac{1}{2}\mu v_{bottom}^2 = G\frac{3\mu M_\oplus}{2R_\oplus}$$

Geometric (x,y) (Dimensionless)	Scaling relations	mks variables (meter-kg-sec)		
space coord.: x	$r = R_\oplus x$	$x = r/R_\oplus$		
PE for $\lvert x\rvert \geq 1$: $y^{PE} = \dfrac{-1}{x}$	$PE^{mks}(r) = \dfrac{GM\mu}{R_\oplus} y^{PE}$	$PE^{mks}(r) = -\dfrac{GM\mu}{r} = -\dfrac{GM\mu}{R_\oplus}\dfrac{1}{x}$	PE for $\lvert x\rvert < 1$: $y^{PE} = \dfrac{x^2}{2} - \dfrac{3}{2}$	$PE^{mks}(r) = \dfrac{GM\mu}{R_\oplus}\left(\dfrac{r^2}{2R_\oplus^2} - \dfrac{3}{2}\right)$
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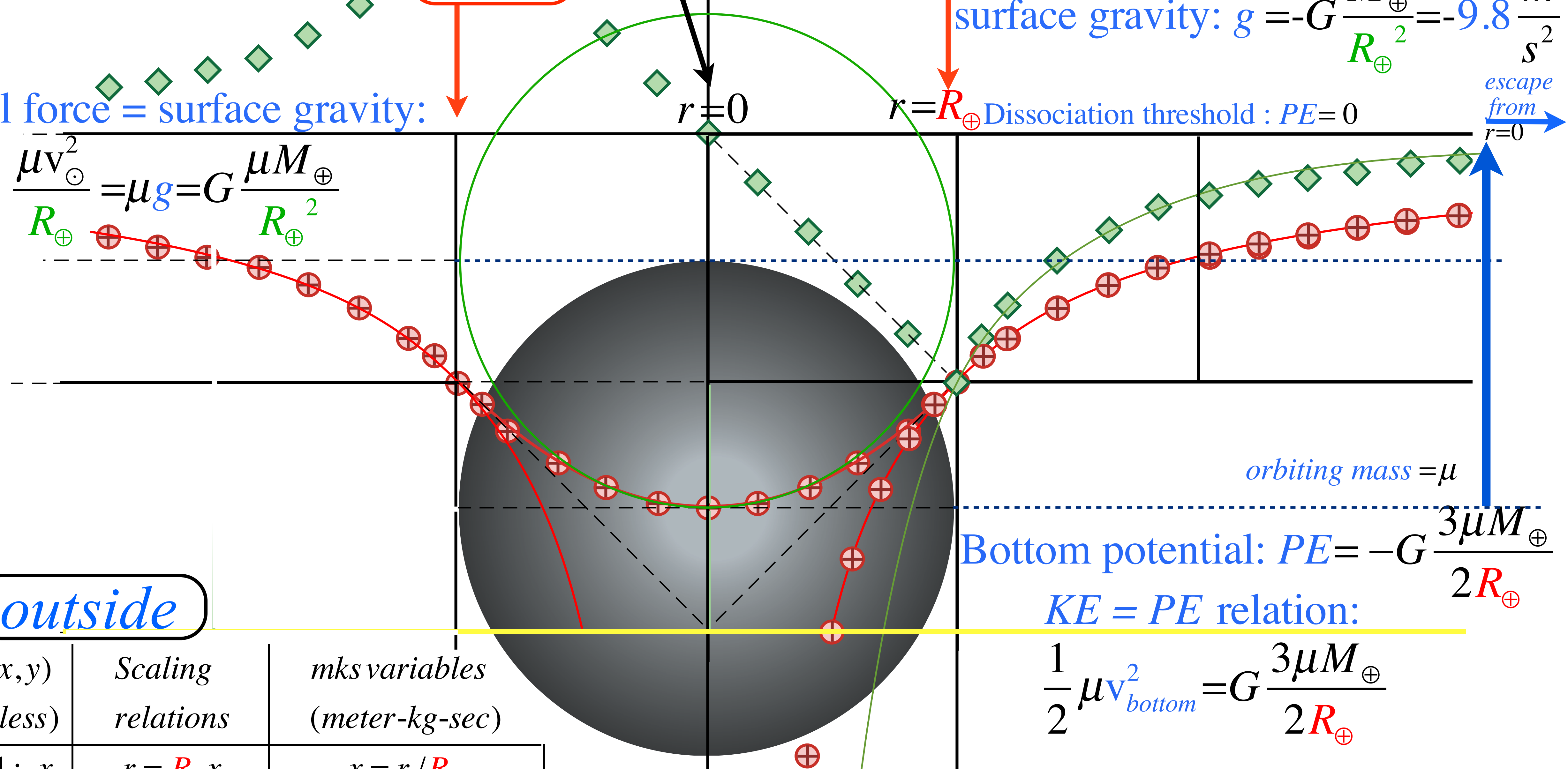
$(r=0)$-escape-velocity

$$v_{bottom} = \sqrt{3G\frac{M_\oplus}{R_\oplus}}$$

13.7km/sec

Sophomore-physics-Earth inside and out:
...and surface orbit at $r=R_\oplus$



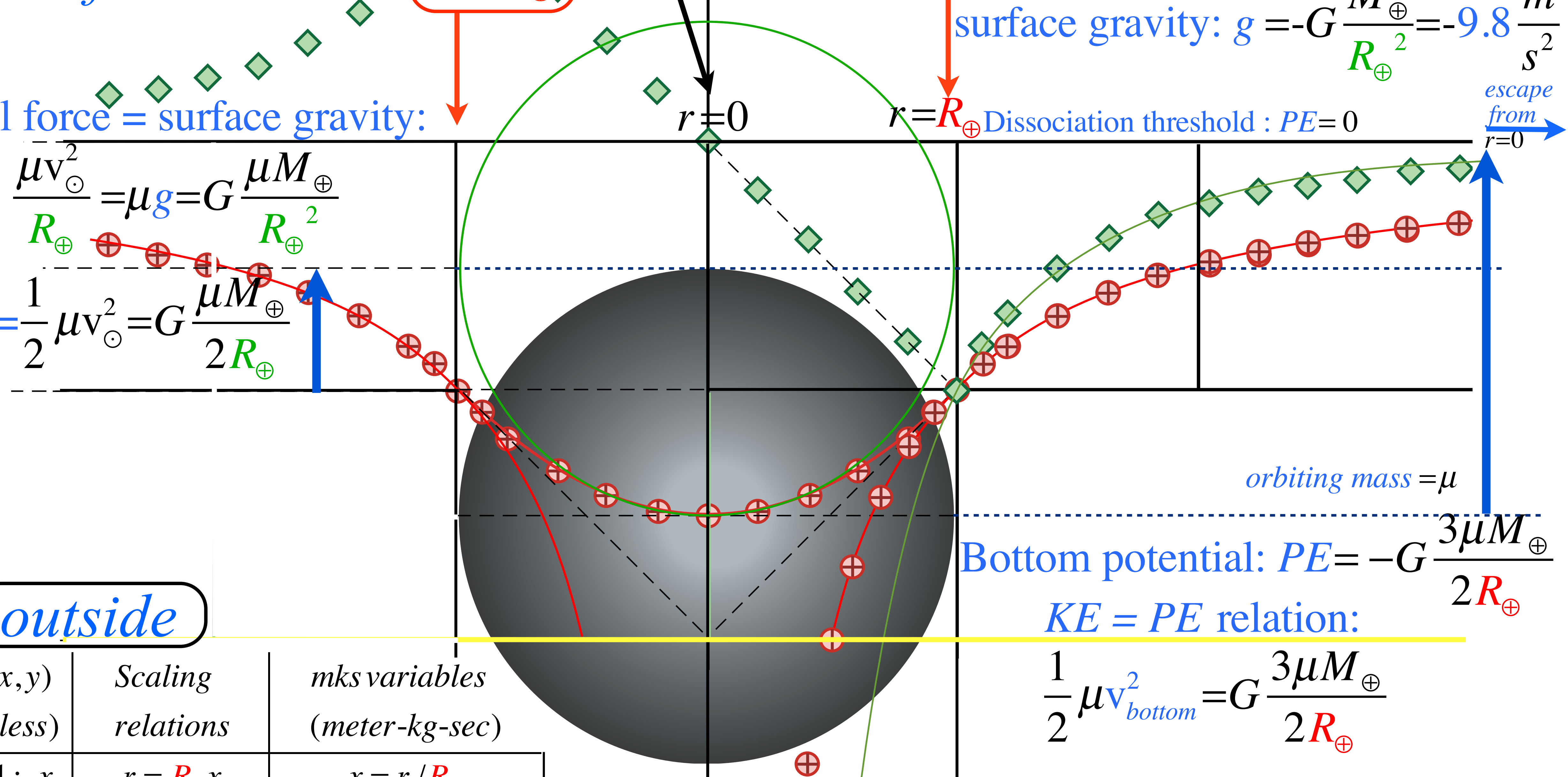
Geometric (x,y) (Dimensionless)	*Scaling relations*	*mks variables (meter-kg-sec)*		
space coord.: x	$r = R_\oplus x$	$x = r/R_\oplus$		
PE for $\lvert x\rvert \geq 1$: $y^{PE} = \frac{-1}{x}$	$PE^{mks}(r) = \frac{GM\mu}{R_\oplus} y^{PE}$	$PE^{mks}(r) = -\frac{GM\mu}{r} = -\frac{GM\mu}{R_\oplus}\frac{1}{x}$	PE for $\lvert x\rvert<1$: $y^{PE} = \frac{x^2}{2} - \frac{3}{2}$	$PE^{mks}(r) = \frac{GM\mu}{R_\oplus}\left(\frac{r^2}{2R_\oplus^2} - \frac{3}{2}\right)$
$Force$ for $\lvert x\rvert \geq 1$: $y^{Force} = \frac{-1}{x^2}$	$F^{mks}(r) = \frac{GM\mu}{R_\oplus^2} y^{Force}$	$F^{mks}(r) = -\frac{GM\mu}{r^2} = -\frac{GM\mu}{R_\oplus^2}\frac{1}{x^2}$	$Force$ for $\lvert x\rvert<1$: $y^{Force} = -x$	$F^{mks}(r) = -\frac{GM\mu}{R_\oplus^3} r$

$(r=0)$-escape-velocity

$v_{bottom} = \sqrt{3G\frac{M_\oplus}{R_\oplus}}$

13.7km/sec

Sophomore-physics-Earth inside and out:
...and surface orbit at $r=R_\oplus$



Geometric (x,y) (*Dimensionless*)	*Scaling relations*	*mks variables* (*meter-kg-sec*)
space coord.: x	$r = R_\oplus x$	$x = r/R_\oplus$
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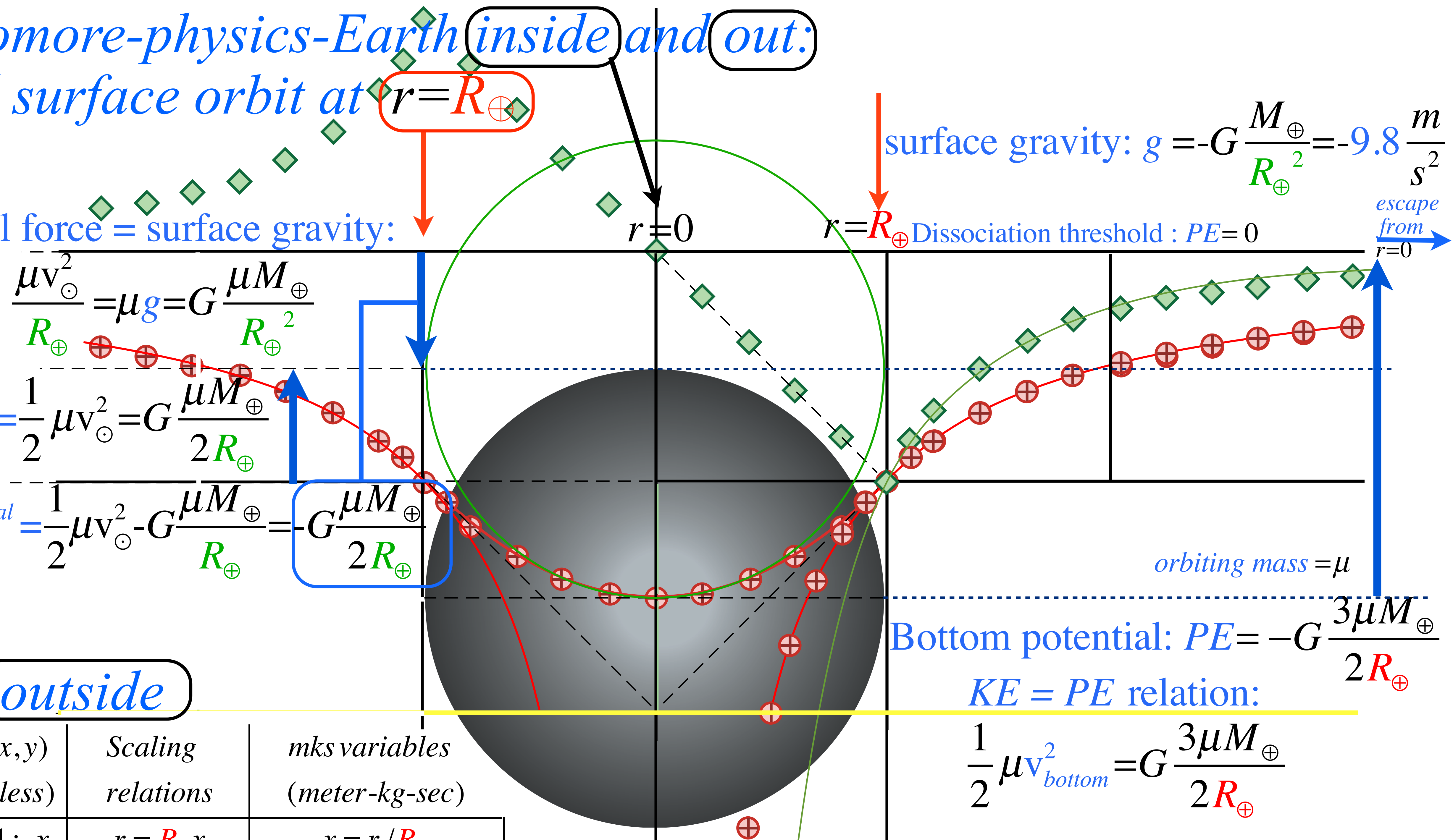

Geometric (x,y) (Dimensionless)	Scaling relations	mks variables (meter-kg-sec)		inside
space coord.: x	$r=R_\oplus x$	$x=r/R_\oplus$		
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$$v_{bottom}=\sqrt{3G\frac{M_\oplus}{R_\oplus}}$$

13.7km/sec

Sophomore-physics-Earth inside and out: "3-steps out of (or into) Hell"

...and surface orbit at $r=R_\oplus$

surface gravity: $g=-G\frac{M_\oplus}{R_\oplus^2}=-9.8\frac{m}{s^2}$

Centifugal force = surface gravity:

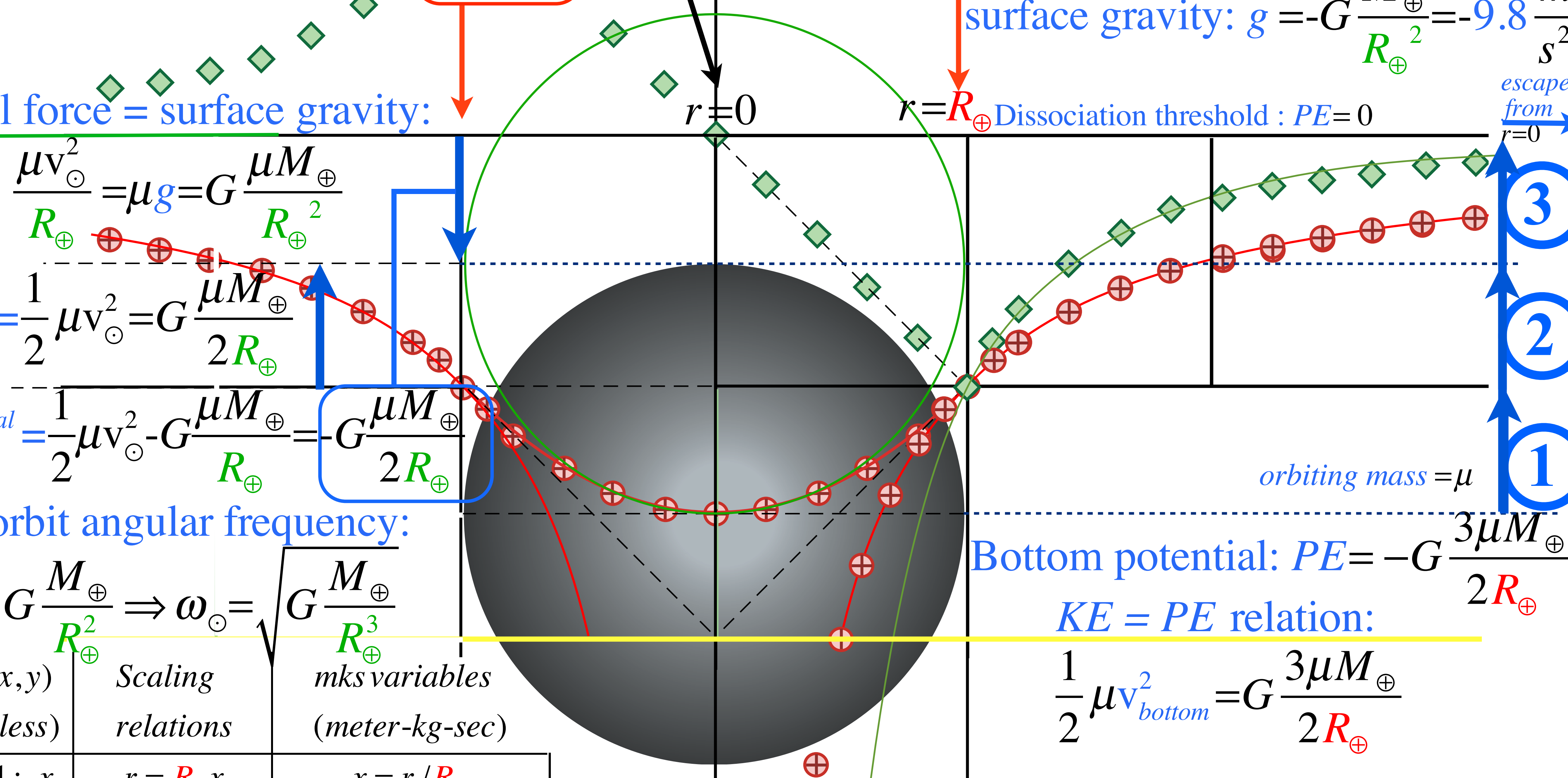
$$\frac{\mu v_\odot^2}{R_\oplus}=\mu g=G\frac{\mu M_\oplus}{R_\oplus^2}$$

Orbit KE $=\frac{1}{2}\mu v_\odot^2=G\frac{\mu M_\oplus}{2R_\oplus}$

Orbit $E_\odot^{Total}=\frac{1}{2}\mu v_\odot^2-G\frac{\mu M_\oplus}{R_\oplus}=-G\frac{\mu M_\oplus}{2R_\oplus}$

$(r=R_\oplus)$-orbit angular frequency:

$$\omega_\odot^2 R_\oplus=G\frac{M_\oplus}{R_\oplus^2}\Rightarrow\omega_\odot=\sqrt{G\frac{M_\oplus}{R_\oplus^3}}$$



Bottom potential: $PE=-G\frac{3\mu M_\oplus}{2R_\oplus}$

KE = PE relation:

$$\frac{1}{2}\mu v_{bottom}^2=G\frac{3\mu M_\oplus}{2R_\oplus}$$

Geometric (x,y) *(Dimensionless)*	*Scaling relations*	*mks variables (meter-kg-sec)*
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	inside
PE for $\lvert x\rvert<1$: $y^{PE}=\frac{x^2}{2}-\frac{3}{2}$	$PE^{mks}(r)=\frac{GM\mu}{R_\oplus}\left(\frac{r^2}{2R_\oplus^2}-\frac{3}{2}\right)$
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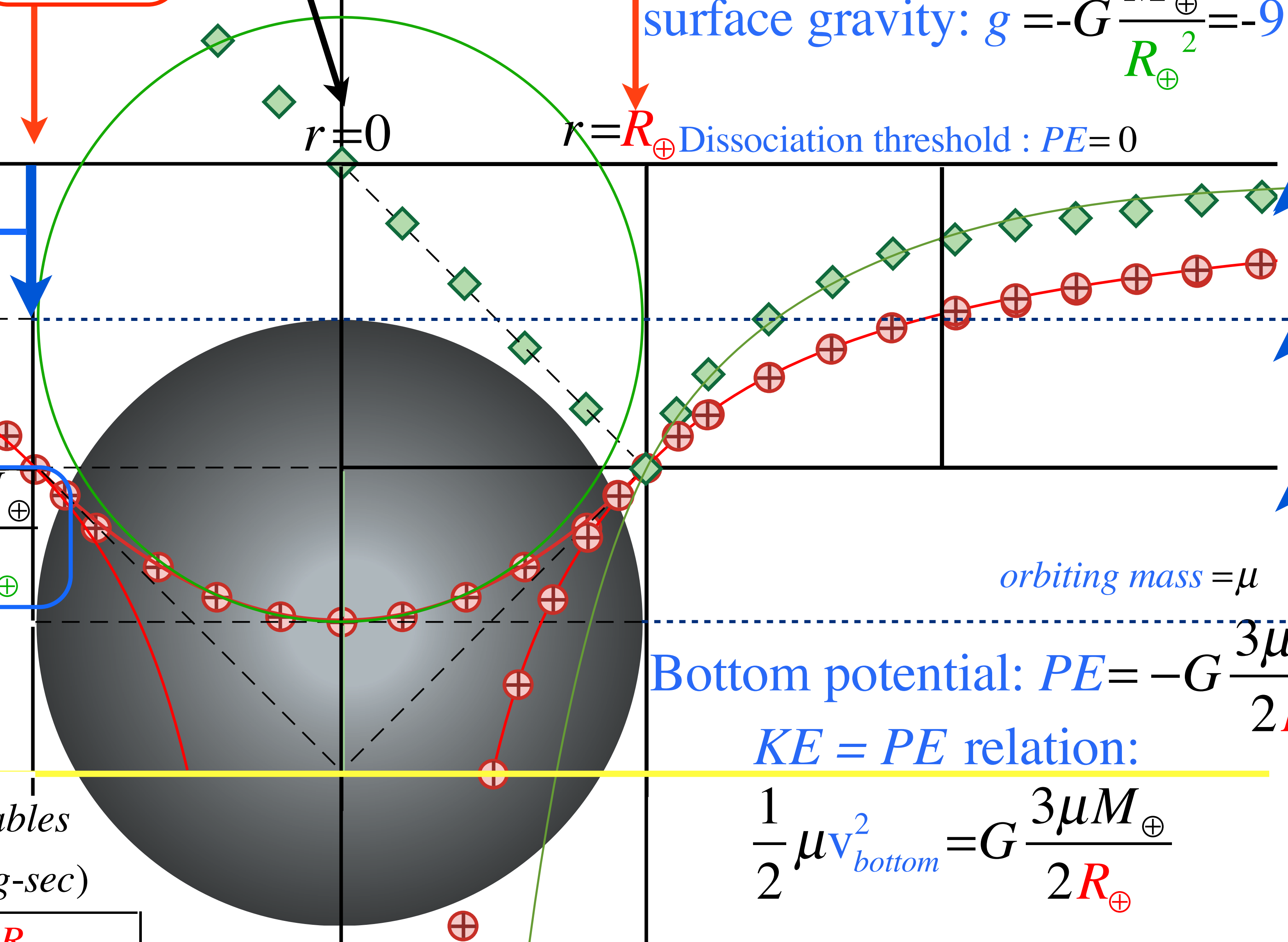

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Geometric (x,y) *(Dimensionless)*	*Scaling relations*	*mks variables (meter-kg-sec)*		*inside*
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$(r=0)$-escape-velocity

$$v_{bottom}=\sqrt{3G\frac{M_\oplus}{R_\oplus}}$$

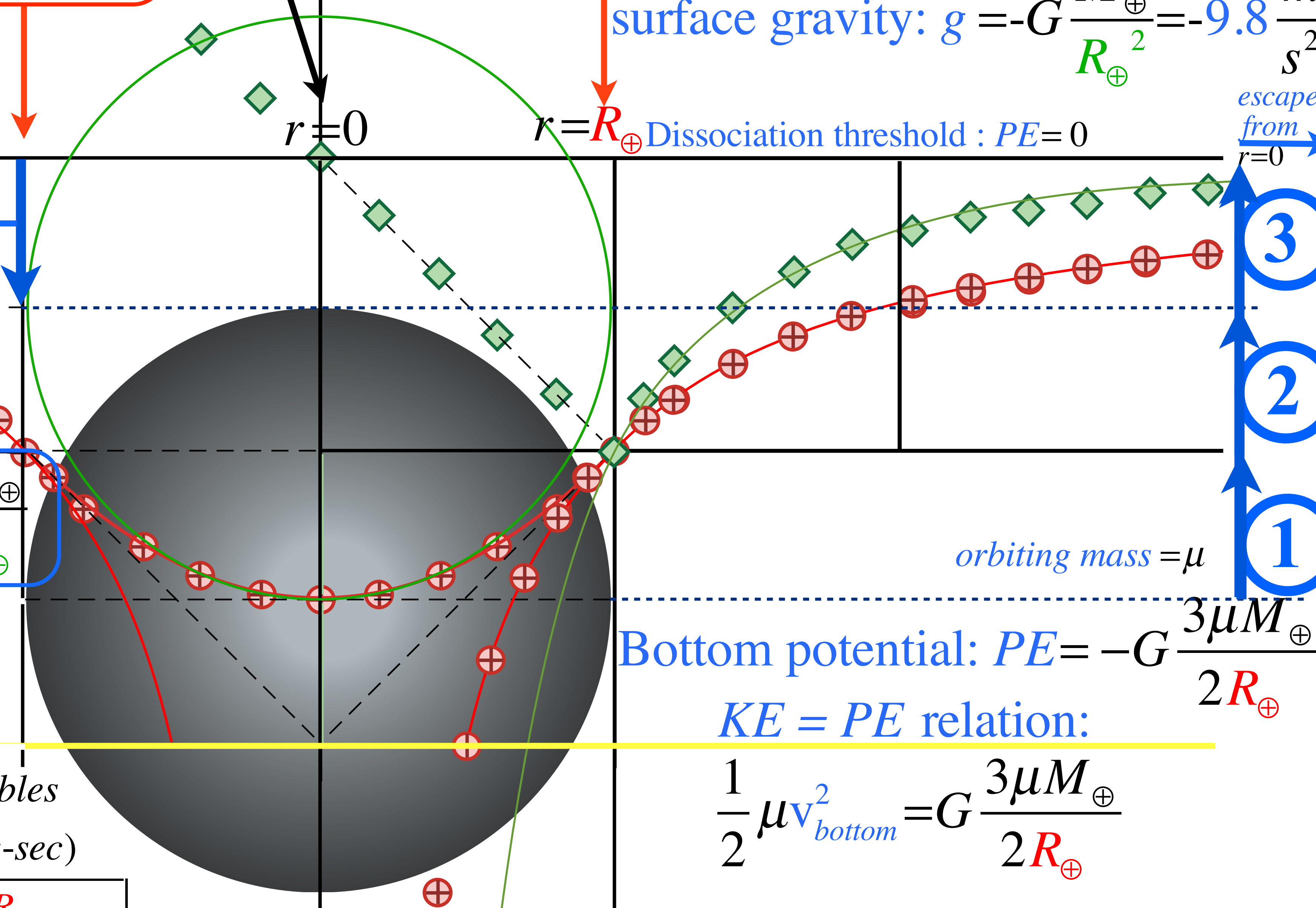
13.7km/sec

$(r=R_\oplus)$-orbit speed:

$$v_\odot=\sqrt{G\frac{M_\oplus}{R_\oplus}}=\sqrt{gR_\oplus}$$

7.9km/sec

Sophomore-physics-Earth inside and out: "3-steps out of (or into) Hell" ...and surface orbit at $r=R_\oplus$



surface gravity: $g=-G\frac{M_\oplus}{R_\oplus^2}=-9.8\frac{m}{s^2}$

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Geometric (x,y) *(Dimensionless)*	*Scaling relations*	*mks variables (meter-kg-sec)*		inside
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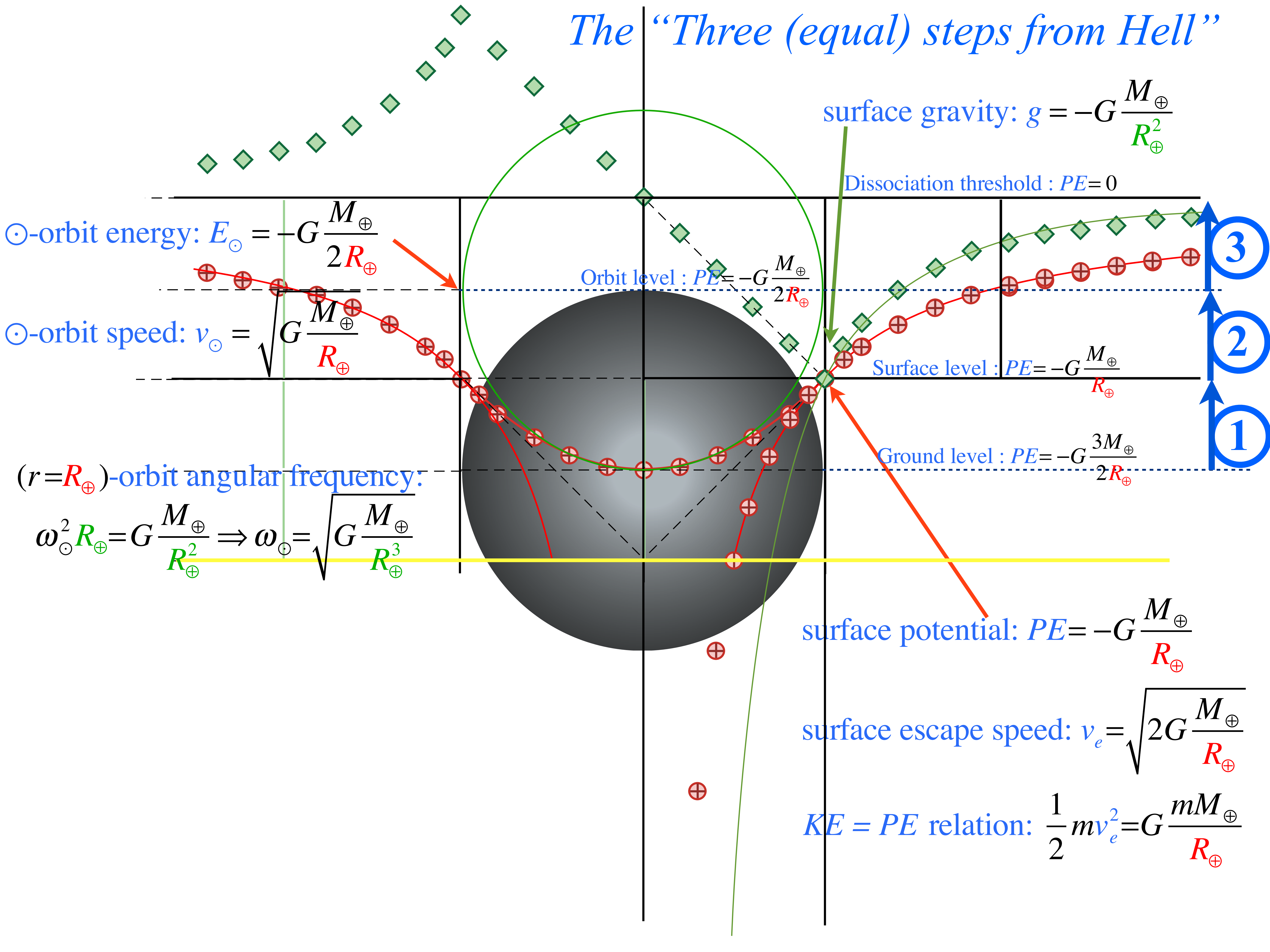
$(r=0)$-escape-velocity

$$v_{bottom}=\sqrt{3G\frac{M_\oplus}{R_\oplus}}$$

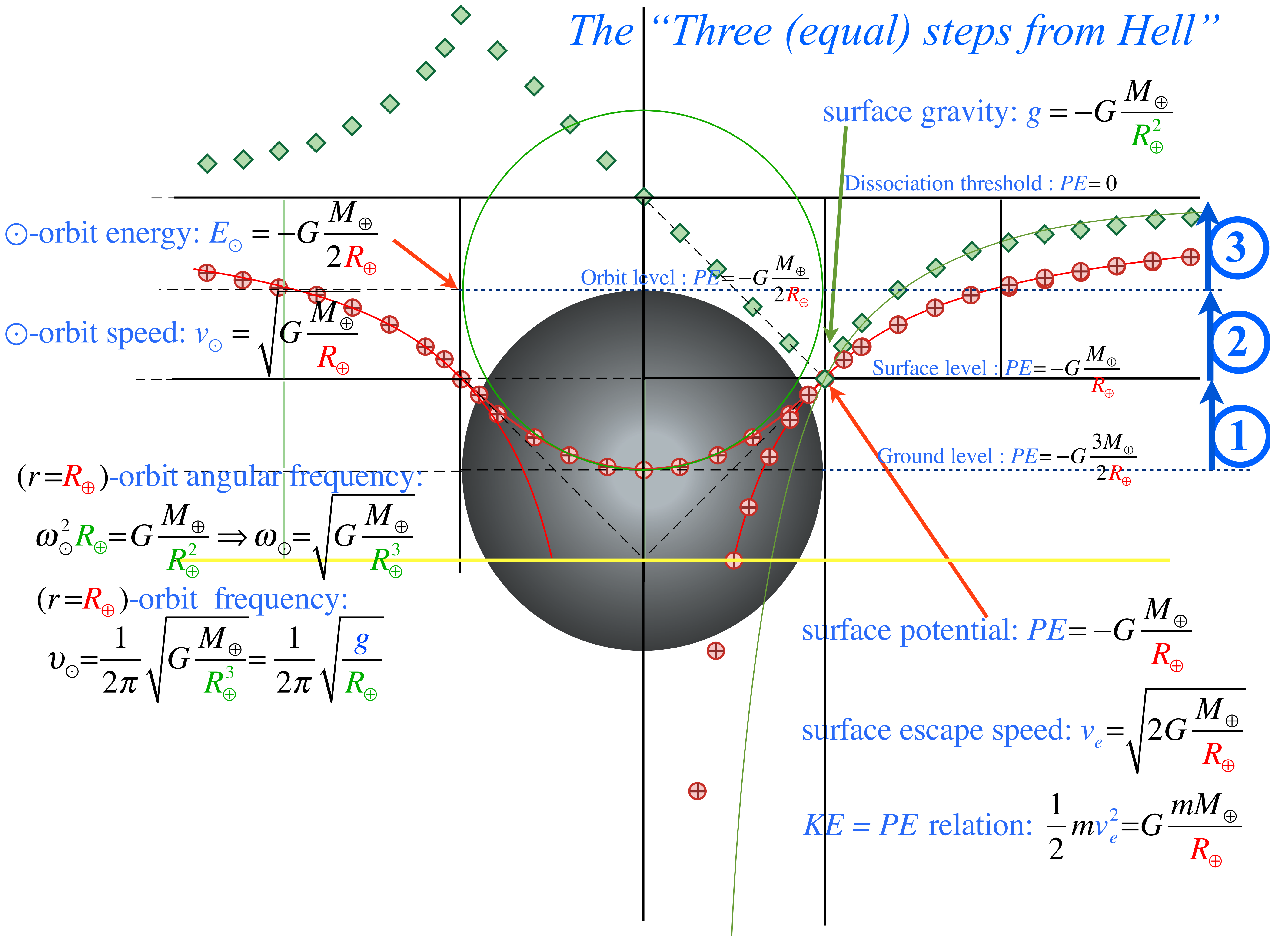
$(r=R_\oplus)$-escape velocity:

$$v_{escape}=\sqrt{2G\frac{M_\oplus}{R_\oplus}}$$

11.1km/sec



The "Three (equal) steps from Hell"
surface gravity: $g = -G\frac{M_\oplus}{R_\oplus^2}$
Dissociation threshold : $PE = 0$
⊙-orbit energy: $E_\odot = -G\frac{M_\oplus}{2R_\oplus}$
Orbit level : $PE = -G\frac{M_\oplus}{2R_\oplus}$
⊙-orbit speed: $v_\odot = \sqrt{G\frac{M_\oplus}{R_\oplus}}$
Surface level : $PE = -G\frac{M_\oplus}{R_\oplus}$
Ground level : $PE = -G\frac{3M_\oplus}{2R_\oplus}$
3
2
1
$(r = R_\oplus)$-orbit angular frequency:
$\omega_\odot^2 R_\oplus = G\frac{M_\oplus}{R_\oplus^2} \Rightarrow \omega_\odot = \sqrt{G\frac{M_\oplus}{R_\oplus^3}}$
surface potential: $PE = -G\frac{M_\oplus}{R_\oplus}$
surface escape speed: $v_e = \sqrt{2G\frac{M_\oplus}{R_\oplus}}$
KE = PE relation: $\frac{1}{2}mv_e^2 = G\frac{mM_\oplus}{R_\oplus}$



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Surface level : $PE = -G\frac{M_\oplus}{R_\oplus}$
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3
2
1
$(r = R_\oplus)$-orbit angular frequency:
$\omega_\odot^2 R_\oplus = G\frac{M_\oplus}{R_\oplus^2} \Rightarrow \omega_\odot = \sqrt{G\frac{M_\oplus}{R_\oplus^3}}$
$(r = R_\oplus)$-orbit frequency:
$\upsilon_\odot = \frac{1}{2\pi}\sqrt{G\frac{M_\oplus}{R_\oplus^3}} = \frac{1}{2\pi}\sqrt{\frac{g}{R_\oplus}}$
surface potential: $PE = -G\frac{M_\oplus}{R_\oplus}$
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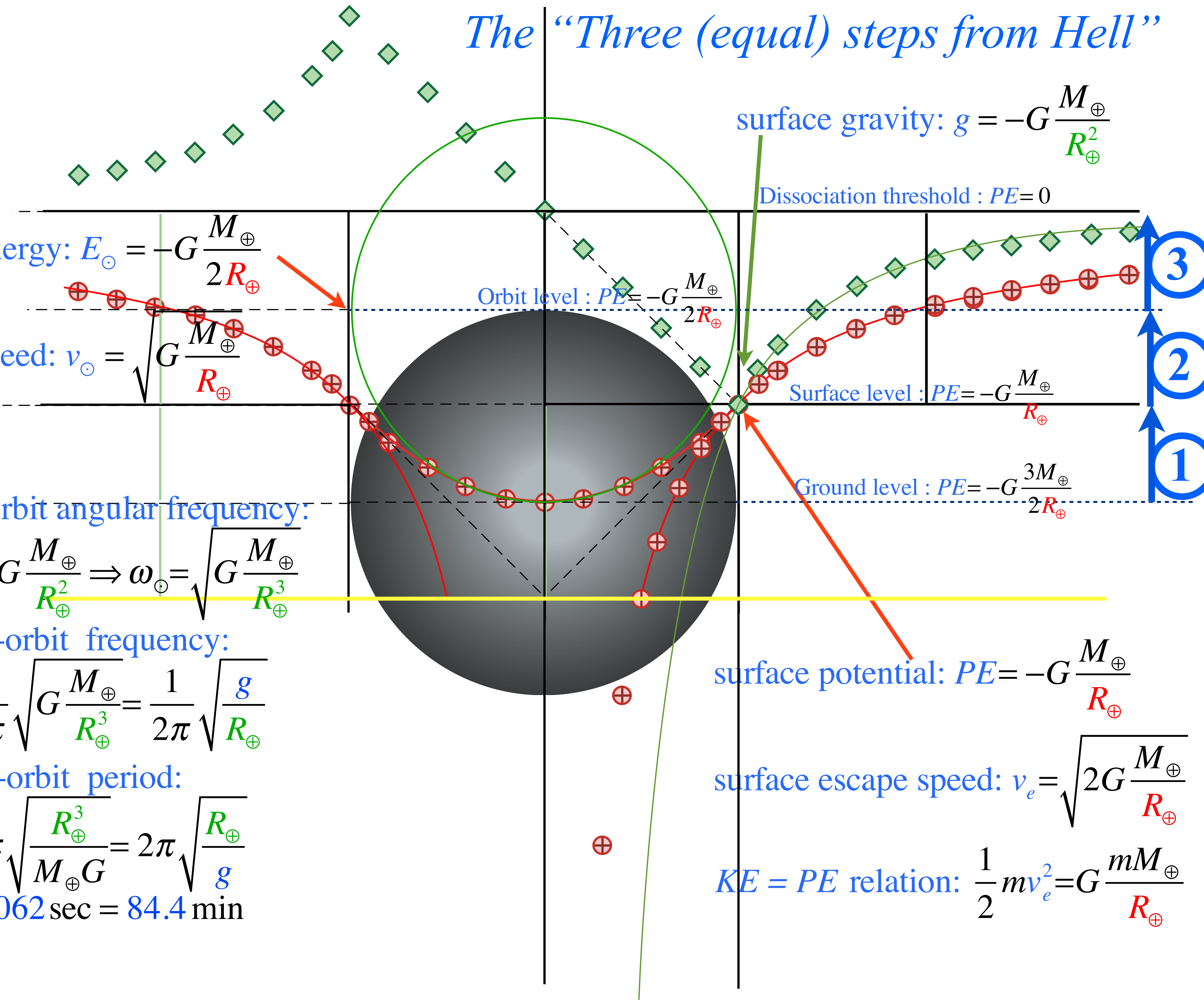
The "Three (equal) steps from Hell"



surface gravity: $g = -G\frac{M_\oplus}{R_\oplus^2}$

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$(r=R_\oplus)$-orbit angular frequency:

$$\omega_\odot^2 R_\oplus = G\frac{M_\oplus}{R_\oplus^2} \Rightarrow \omega_\odot = \sqrt{G\frac{M_\oplus}{R_\oplus^3}}$$

$(r=R_\oplus)$-orbit frequency:

$$\upsilon_\odot = \frac{1}{2\pi}\sqrt{G\frac{M_\oplus}{R_\oplus^3}} = \frac{1}{2\pi}\sqrt{\frac{g}{R_\oplus}}$$

$(r=R_\oplus)$-orbit period:

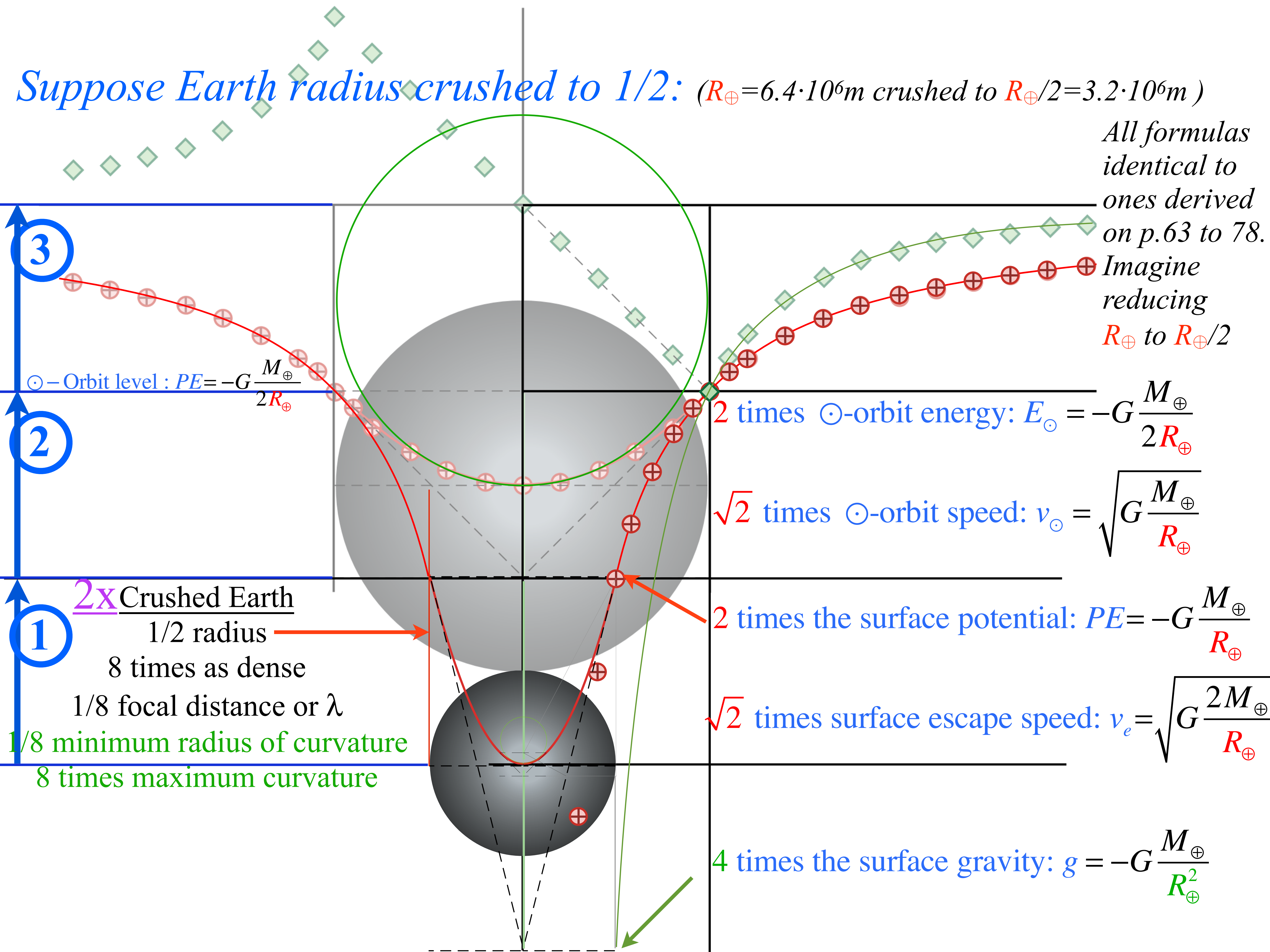
$$\upsilon_\odot = 2\pi\sqrt{\frac{R_\oplus^3}{M_\oplus G}} = 2\pi\sqrt{\frac{R_\oplus}{g}}$$

$= 5062\,\text{sec} = 84.4\,\text{min}$

surface potential: $PE = -G\frac{M_\oplus}{R_\oplus}$

surface escape speed: $v_e = \sqrt{2G\frac{M_\oplus}{R_\oplus}}$

KE = PE relation: $\frac{1}{2}mv_e^2 = G\frac{mM_\oplus}{R_\oplus}$



Suppose Earth radius crushed to 1/2:
($R_\oplus$=6.4·10^{6}m crushed to $R_\oplus$/2=3.2·10^{6}m)
All formulas identical to ones derived on p.63 to 78.
Imagine reducing $R_\oplus$ to $R_\oplus$/2
3
2
1
$\odot$ – Orbit level : $PE = -G\frac{M_\oplus}{2R_\oplus}$
2 times $\odot$-orbit energy: $E_\odot = -G\frac{M_\oplus}{2R_\oplus}$
$\sqrt{2}$ times $\odot$-orbit speed: $v_\odot = \sqrt{G\frac{M_\oplus}{R_\oplus}}$
2x Crushed Earth
1/2 radius
8 times as dense
1/8 focal distance or λ
1/8 minimum radius of curvature
8 times maximum curvature
2 times the surface potential: $PE = -G\frac{M_\oplus}{R_\oplus}$
$\sqrt{2}$ times surface escape speed: $v_e = \sqrt{G\frac{2M_\oplus}{R_\oplus}}$
4 times the surface gravity: $g = -G\frac{M_\oplus}{R_\oplus^2}$

Geometry of idealized "Sophomore-physics Earth"

Coulomb field <u>outside</u> *Isotropic Harmonic Oscillator (IHO) field <u>inside</u>*

Contact-geometry of potential curve(s)

"Crushed-Earth" models: 3 key energy "steps" and 4 key energy "levels"

Earth matter vs nuclear matter:

→ *Introducing the "neutron starlet" and "***Black-Hole-Earth***"*

Examples of "crushed" matter

Earth matter

Earth mass : $M_{\oplus} = 5.9722 \times 10^{24}\,kg. \simeq 6.0 \cdot 10^{24}\,kg.$ Density $\rho_{\oplus}$ $= ??$

Earth radius : $R_{\oplus} = 6.371 \cdot 10^{6}\,m \simeq 6.4 \cdot 10^{6}\,m$ *Earth volume* : $(4\pi/3)R_{\oplus}^{3} \simeq 4 \cdot 260 \cdot 10^{18} \sim 10^{21}\,m^{3}$

$(6.4)^3 \sim 262$ and $(4\pi/3)260 = 1098 \sim 10^3$

Examples of "crushed" matter

$$\rho_\oplus = \frac{M_\oplus}{(4\pi/3)R_\oplus{}^3}$$

Earth matter

$Earth\,mass: M_\oplus = 5.9722\times 10^{24}\,kg. \simeq 6.0\cdot 10^{24}\,kg.$ Density $\rho_\oplus \sim 6.0\cdot 10^{24-21} \sim 6\cdot 10^3 kg/m^3$

$Earth\,radius: R_\oplus = 6.371\cdot 10^6\,m \simeq 6.4\cdot 10^6\,m$ $\quad Earth\,volume: (4\pi/3)R_\oplus^3 \simeq 4\cdot 260\cdot 10^{18} \sim 10^{21}\,m^3$

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$(6.4)^3 \sim 262$ and $(4\pi/3)260 = 1089 \sim 10^3$

Density of solid Fe$=7.9 \cdot 10^3 kg/m^3$
Density of liquid Fe$=6.9 \cdot 10^3 kg/m^3$

Examples of "crushed" matter

$$\rho_\oplus = \frac{M_\oplus}{(4\pi/3)R_\oplus{}^3}$$

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Nuclear matter

Nucleon mass $=1.67 \cdot 10^{-27} kg. \sim 2 \cdot 10^{-27} kg.$ *("fingertip physics")*

Say a nucleus of atomic weight *50* has a radius of *3 fm*, or *50* nucleons each with a mass $2 \cdot 10^{-27} kg$.

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That's $100 \cdot 10^{-27} = 10^{-25}\ kg$ packed into a volume of $^{4\pi}/_3 r^3 = {}^{4\pi}/_3\ (3 \cdot 10^{-15})^3\ m^3$ or about $10^{-43}\ m^3$.

$[4\pi 3^2 = 36\pi = 113 \sim 10^2]10^{-45}$

Examples of "crushed" matter

$$\rho_\oplus = \frac{M_\oplus}{(4\pi/3)R_\oplus{}^3}$$

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$[4\pi 3^2 = 36\pi = 113 \sim 10^2]\, 10^{-45}$

Nuclear density is $10^{-25+43} = 10^{18} kg/m^3$ or a *trillion* (10^{12}) kilograms in a fingertip$(1\text{cm})^3$.

$(1cm)^3 = (10^{-2}m)^3 = 10^{-6}m^3$

Examples of "crushed" matter

$$\rho_\oplus = \frac{M_\oplus}{(4\pi/3)R_\oplus^{\ 3}}$$

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$(1cm)^3=(10^{-2}m)^3=10^{-6}m^3$

Earth radius crushed by a factor of $0.5\cdot 10^{-5}$ to $R_{crush\oplus} \simeq 300m$ would approach neutron-star density.

Geometry and algebra of idealized "Sophomore-physics Earth" fields

Coulomb field outside *Isotropic Harmonic Oscillator (IHO) field inside*

Contact-geometry of potential curve(s) and "kite" geometry

"Ordinary-Earth" models: 3 key energy "steps" and 4 key energy "levels"

"Crushed-Earth" models: 3 key energy "steps" and 4 key energy "levels"

Earth matter vs nuclear matter:

→ *Introducing the "neutron starlet"*

*Fantasizing a "***Black-Hole-Earth***"*

Examples of "crushed" matter

$$\rho_{\oplus} = \frac{M_{\oplus}}{(4\pi/3)R_{\oplus}^{\ 3}}$$

Earth matter

Earth mass : $M_{\oplus} = 5.9722 \times 10^{24}\,kg. \simeq 6.0 \cdot 10^{24}\,kg.$ Density $\rho_{\oplus}$~ $6.0 \cdot 10^{24-21}$ ~$6 \cdot 10^{3} kg/m^{3}$

Earth radius : $R_{\oplus} = 6.371 \cdot 10^{6}\,m \simeq 6.4 \cdot 10^{6}\,m$ *Earth volume* : $(4\pi/3)R_{\oplus}^{3} \simeq 4 \cdot 260 \cdot 10^{18} \sim 10^{21}\,m^{3}$

Nuclear matter

Nucleon mass $=1.67 \cdot 10^{-27}kg. \sim 2 \cdot 10^{-27}kg.$

Say a nucleus of atomic weight *50* has a radius of *3 fm*, or *50* nucleons each with a mass $2 \cdot 10^{-27}kg$.

That's $100 \cdot 10^{-27} = 10^{-25}\ kg$ packed into a volume of ${}^{4\pi}/_{3}r^{3} = {}^{4\pi}/_{3}\ (3 \cdot 10^{-15})^{3}\ m^{3}$ or about $10^{-43}\ m^{3}$.

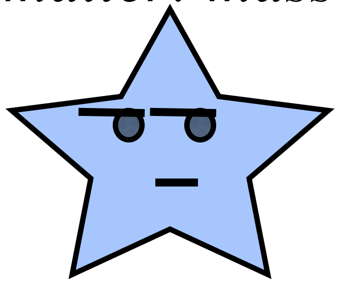
$[4\pi 3^{2} = 36\pi = 113 \sim 10^{2}]10^{-45}$

Nuclear density is $10^{-25+43} = 10^{18} kg\ /m^{3}$ or a *trillion* (10^{12}) kilograms in the size of a fingertip.

Earth radius crushed by a factor of $0.5 \cdot 10^{-5}$ to $R_{crush\oplus} \simeq 300\,m$ would approach neutron-star density.

Introducing the "Neutron starlet"

1 cm^{3} *of nuclear matter: mass*= 10^{12} *kg.*



Geometry and algebra of idealized "Sophomore-physics Earth" fields

Coulomb field outside *Isotropic Harmonic Oscillator (IHO) field inside*

Contact-geometry of potential curve(s) and "kite" geometry

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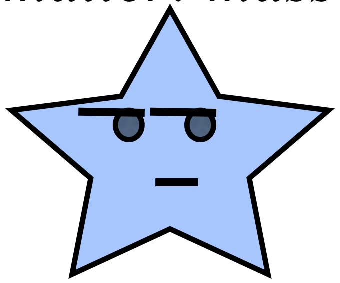

*Fantasizing the "***Black Hole Earth***"*

Suppose Earth is crushed so that its surface escape velocity is the speed of light $c \cong 3.0 \cdot 10^8 m/s$.

$c \equiv 299,792,458 m/s$ (EXACTLY)

$$V_{escape} = \sqrt{(2GM/R_{\otimes})}$$

(from p. 67,..,82)

$G = 6.673 \cdot 10^{-11} Nm^2/C^2$

$\sim (2/3) 10^{-10}$

(from p. 60)

Uncrushed Earth radius : $R_{\oplus} = 6.371 \cdot 10^6 m \simeq 6.4 \cdot 10^6 m$

Earth mass : $M_{\oplus} = 5.9722 \times 10^{24} kg. \simeq 6.0 \cdot 10^{24} kg.$

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$$\rho_\oplus = \frac{M_\oplus}{(4\pi/3)R_\oplus^{\ 3}}$$

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Nuclear matter

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Introducing the "Neutron starlet"

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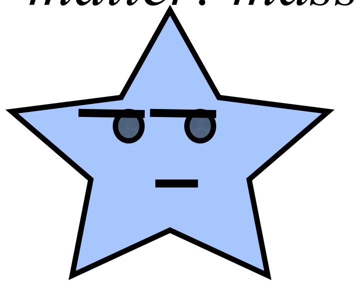

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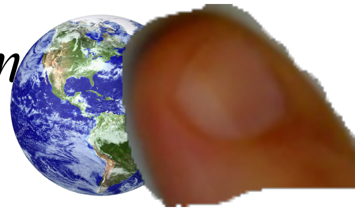
$G = 6.673 \cdot 10^{-11} Nm^2/C^2$

$\sim (2/3) 10^{-10}$

(from p. 60)

$$R_\otimes = 2GM/c^2 = 2\,{}^2/_3 10^{-10}\,6 \cdot 10^{24}/(9 \cdot 10^{16}) = {}^8/_9 10^{-2} = 8.9mm \sim 1cm$$

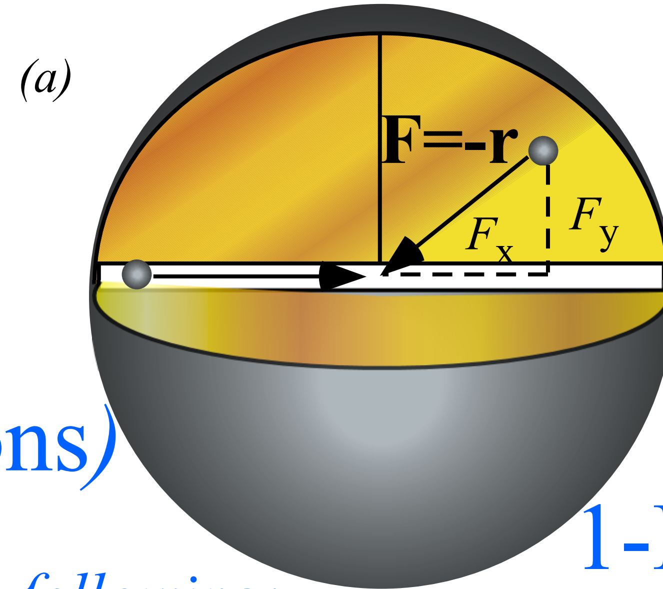


(Then Earth would be fingertip size!)

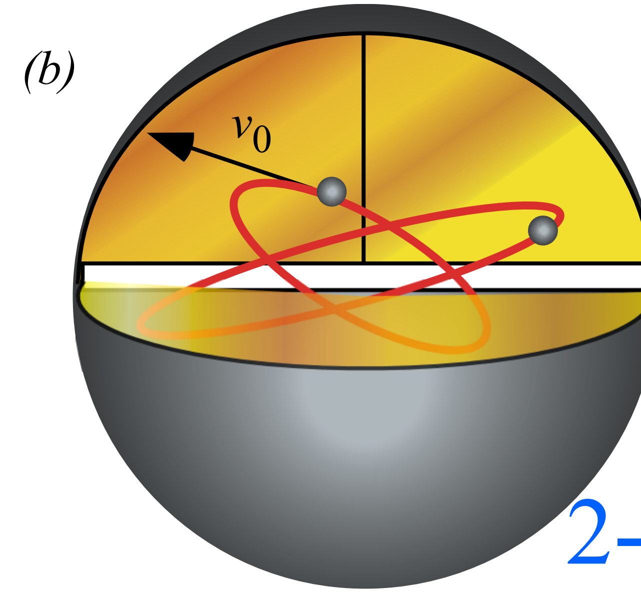
→ *Introducing 2D IHO orbits and phasor geometry*

Phasor "clock" geometry

Isotropic Harmonic Oscillator phase dynamics in uniform-body



1-D



Unit 1
Fig. 9.10

2-D

(Paths are *always* 2-D ellipses if viewed right!)

I.H.O. Force law

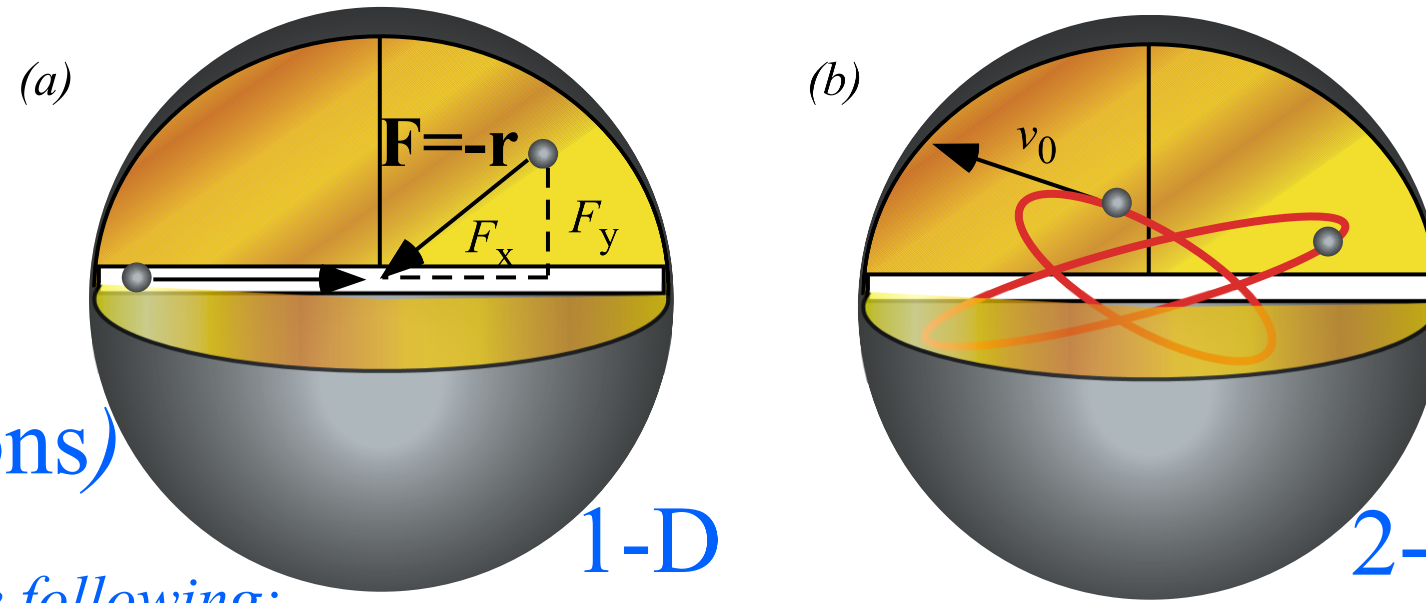
F =-*x* (1-Dimension)

F =-**r** (2 or 3-Dimensions)

Each dimension x, y, or z obeys the following:

$$Total\ E = KE + PE = \frac{1}{2}mv^2 + U(x) = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = const.$$

Isotropic Harmonic Oscillator phase dynamics in uniform-body



1-D

2-D or 3-D

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Unit 1
Fig. 9.10

I.H.O. Force law

$F = -x$ *(*1-Dimension*)*

$\mathbf{F} = -\mathbf{r}$ *(*2 or 3-Dimensions*)*

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Isotropic Harmonic Oscillator phase dynamics in uniform-body

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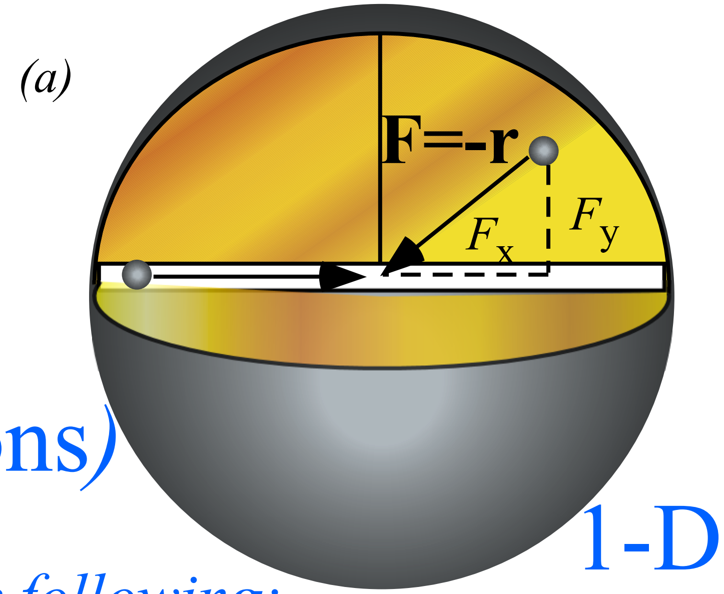

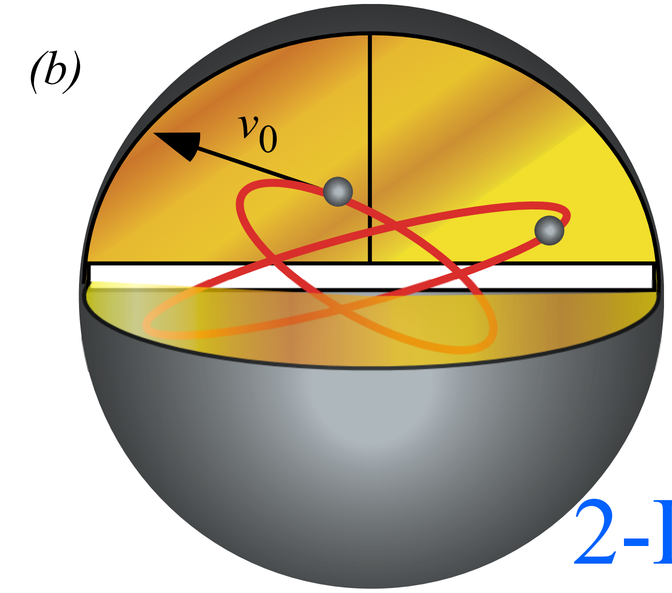

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Unit 1
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$$1 = \frac{mv^2}{2E} + \frac{kx^2}{2E} = \left(\frac{v}{\sqrt{2E/m}}\right)^2 + \left(\frac{x}{\sqrt{2E/k}}\right)^2$$

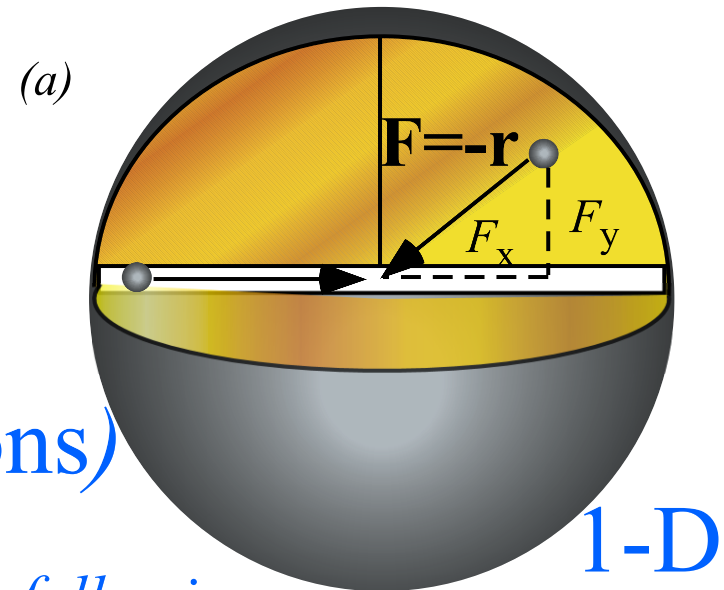
$$1 = \frac{mv^2}{2E} + \frac{kx^2}{2E} = (\cos\theta)^2 + (\sin\theta)^2$$

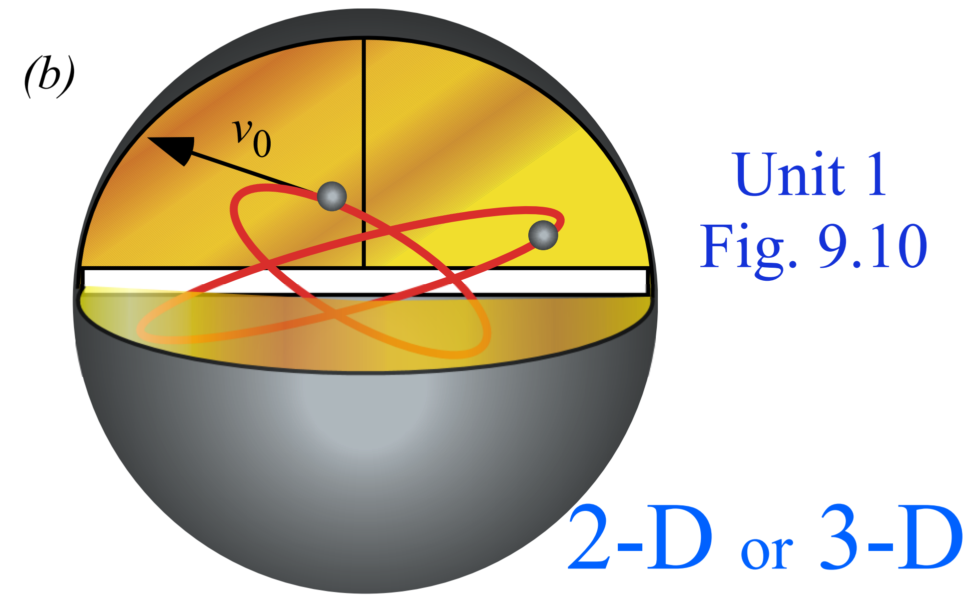
Another example of the old "scale-a-circle" trick...

velocity: *position:*

$$Let:\ \textbf{(1)}\ v = \sqrt{2E/m}\cos\theta, \quad and:\ \textbf{(2)}\ x = \sqrt{2E/k}\sin\theta$$

Isotropic Harmonic Oscillator phase dynamics in uniform-body





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Unit 1
Fig. 9.10

I.H.O. Force law

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Isotropic Harmonic Oscillator phase dynamics in uniform-body

I.H.O. Force law

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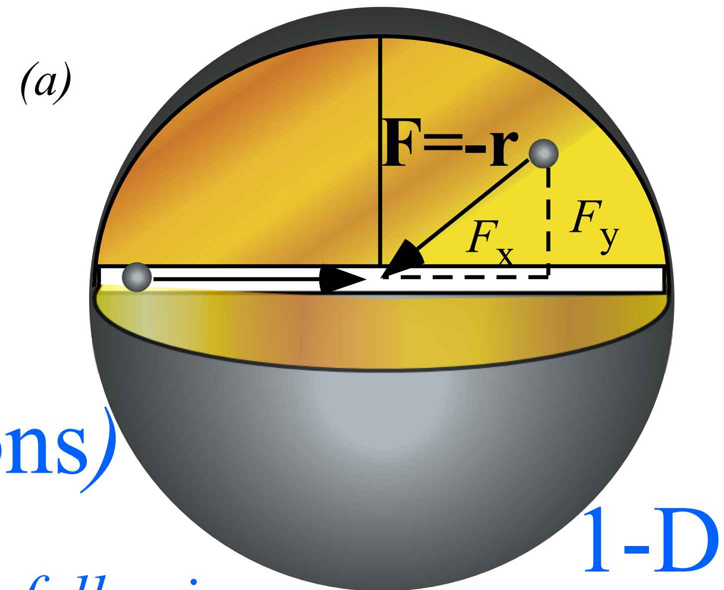
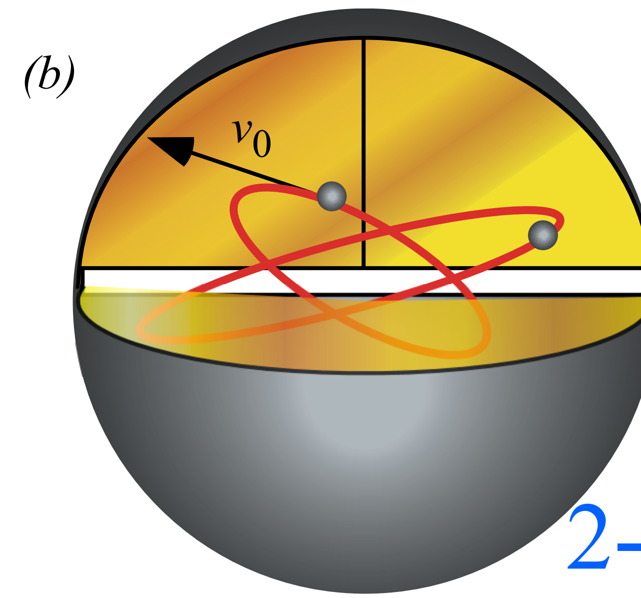
(a)



1-D

(b)



Unit 1 Fig. 9.10

2-D or 3-D

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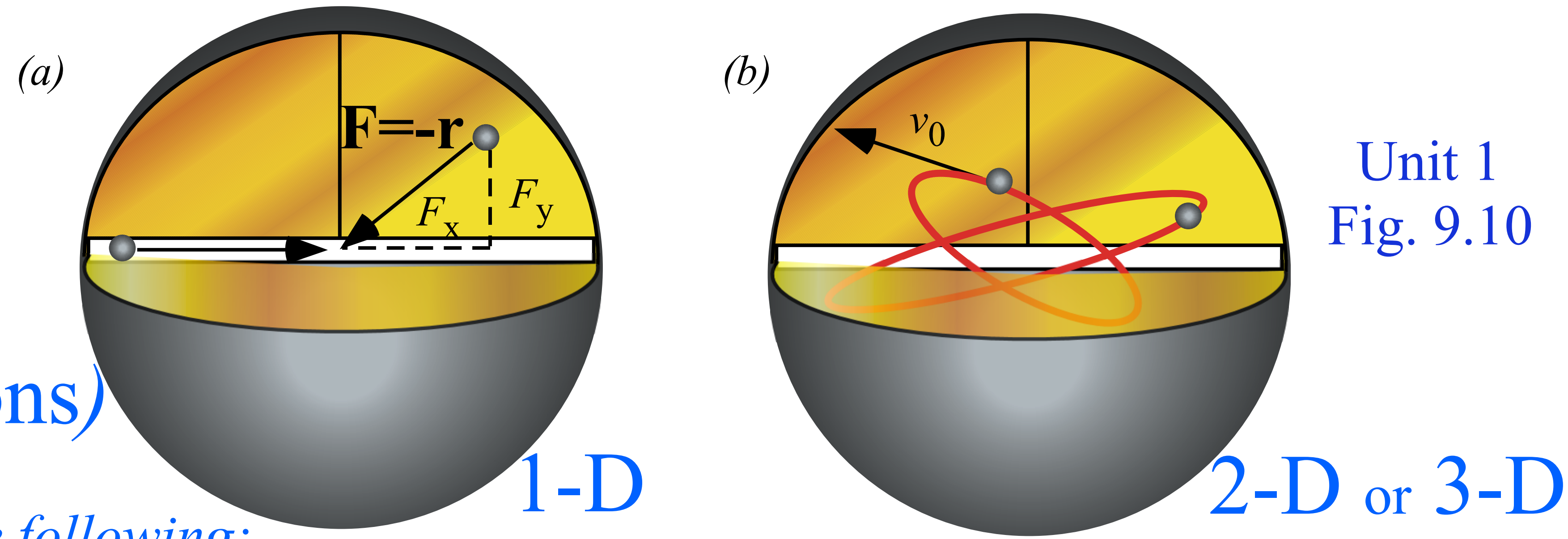
angular velocity: *def.* **(3)** $\omega = \frac{d\theta}{dt}$

$$\sqrt{\frac{2E}{m}}\cos\theta = v = \frac{dx}{dt}$$

by **(1)**

Isotropic Harmonic Oscillator phase dynamics in uniform-body



Unit 1
Fig. 9.10

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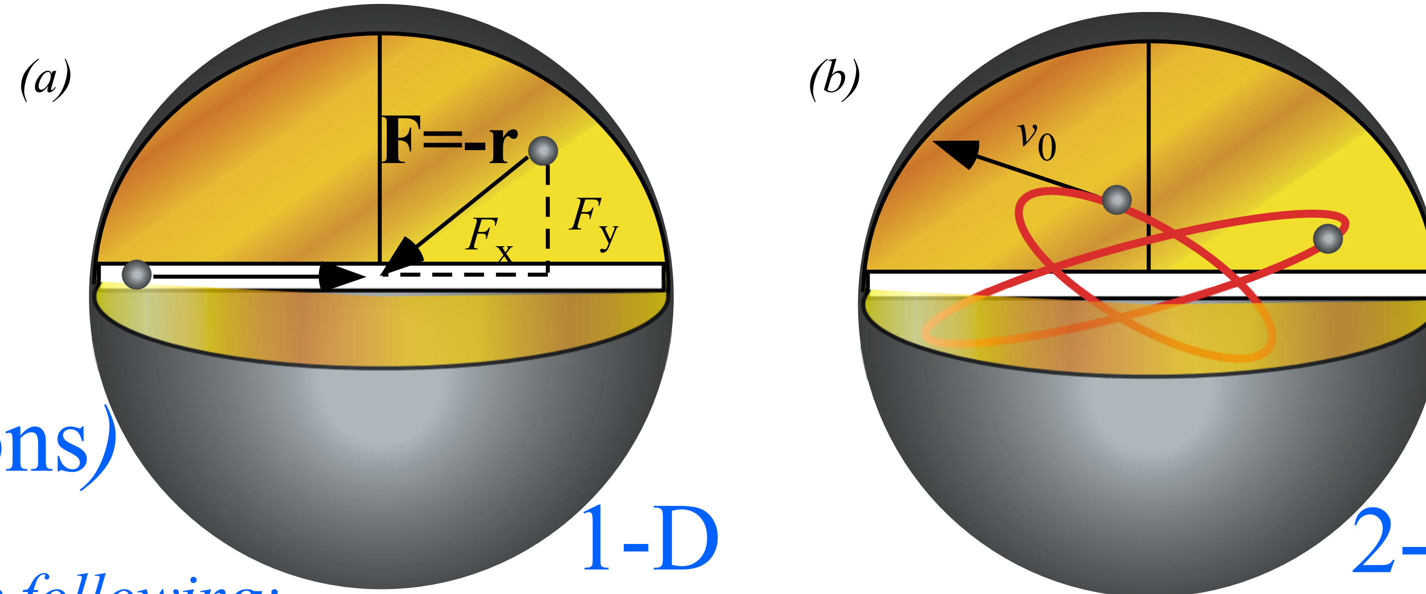
$$\underbrace{\sqrt{\frac{2E}{m}}\cos\theta = v}_{by\ (1)} = \frac{dx}{dt} = \frac{d\theta}{dt}\frac{dx}{d\theta}$$

Isotropic Harmonic Oscillator phase dynamics in uniform-body



Unit 1
Fig. 9.10

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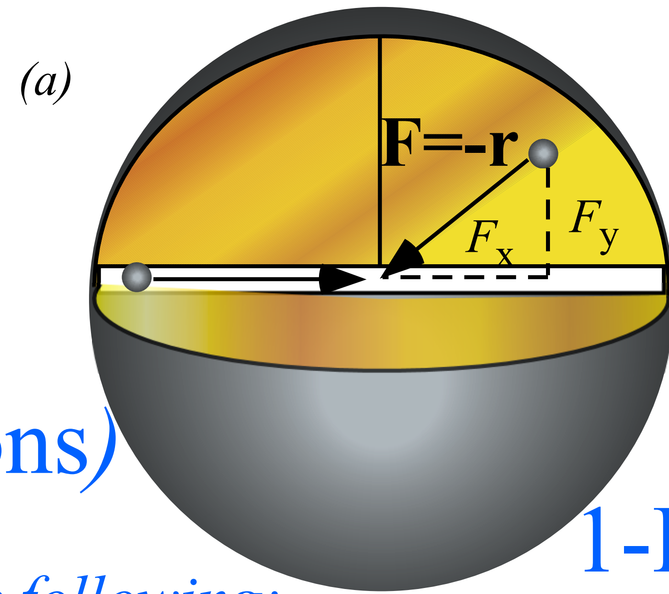
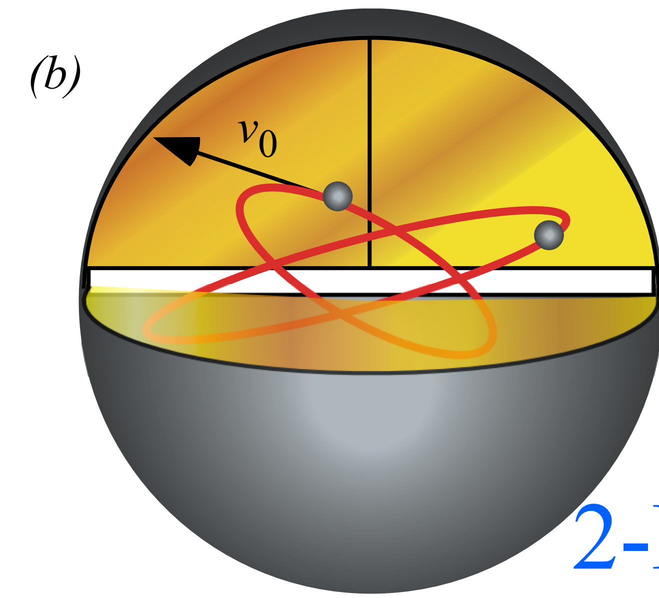
$$\sqrt{\frac{2E}{m}}\cos\theta = v = \frac{dx}{dt} = \frac{d\theta}{dt}\frac{dx}{d\theta} = \omega\frac{dx}{d\theta}$$

by **(1)** *by def.* **(3)**

Isotropic Harmonic Oscillator phase dynamics in uniform-body





Unit 1
Fig. 9.10

I.H.O. Force law

F =-x (1-Dimension)

F =-**r** (2 or 3-Dimensions)

1-D

2-D or 3-D

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by **(1)** *by def.* **(3)** *by* **(2)**

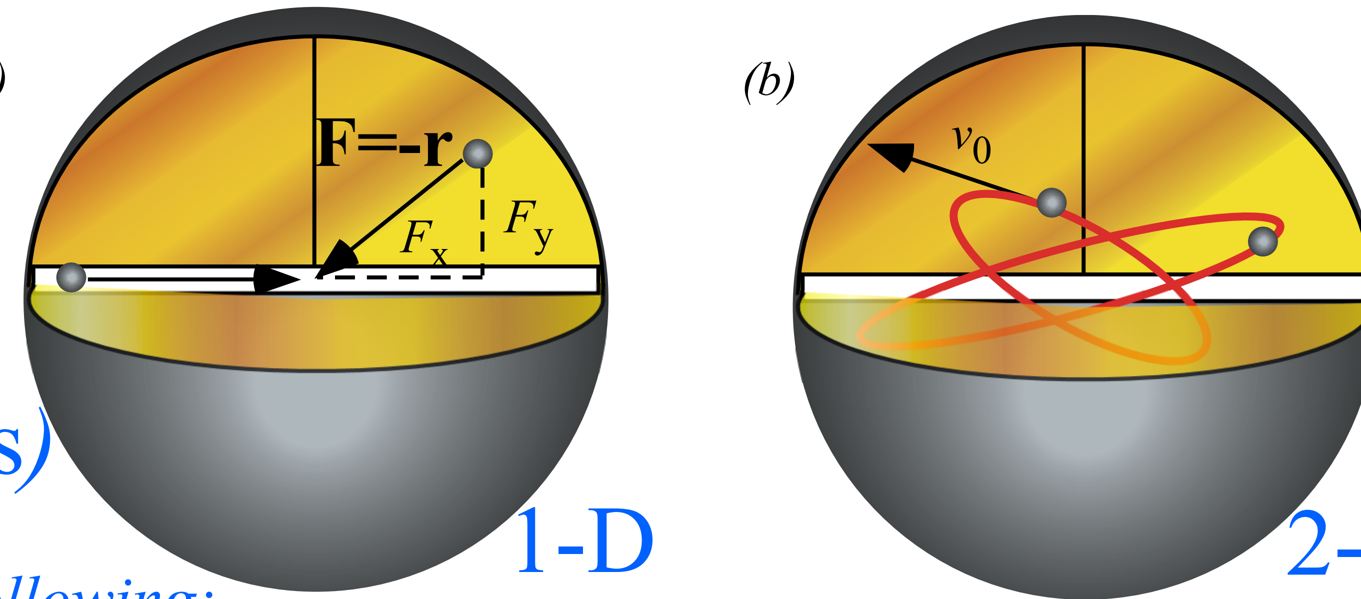
Isotropic Harmonic Oscillator phase dynamics in uniform-body

I.H.O. Force law

F =-x (1-Dimension)

F =-**r** (2 or 3-Dimensions)

(a)



1-D

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Unit 1
Fig. 9.10

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$$Let:\ (1)\ v = \sqrt{2E/m}\cos\theta, \quad and:\ (2)\ x = \sqrt{2E/k}\sin\theta$$

def. (3) $\omega = \frac{d\theta}{dt}$

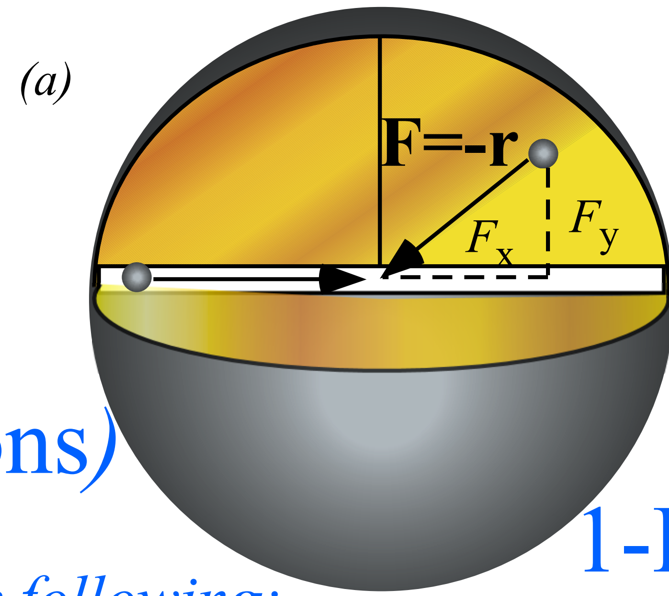
$$\sqrt{\frac{2E}{m}}\cos\theta = v = \frac{dx}{dt} = \frac{d\theta}{dt}\frac{dx}{d\theta} = \omega\frac{dx}{d\theta} = \omega\sqrt{\frac{2E}{k}}\cos\theta$$

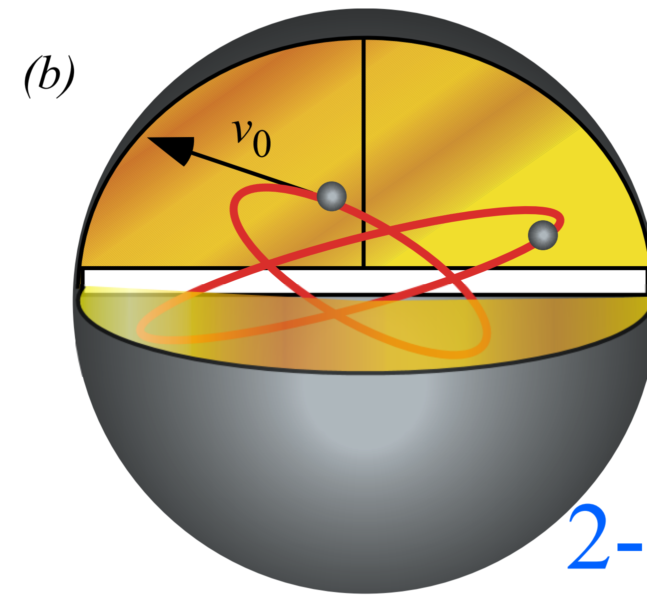
by (1) — *by def.* (3) — *by* (2)

by def. (3)

$$\omega = \frac{d\theta}{dt}$$

Isotropic Harmonic Oscillator phase dynamics in uniform-body





Unit 1
Fig. 9.10

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Equations for x-motion [x(t) and v_x=v(t)] are given first. They apply as well to dimensions [y(t) and v_y=v(t)] and [z(t) and v_z=v(t)] in the ideal isotropic case.

$$1 = \frac{mv^2}{2E} + \frac{kx^2}{2E} = \left(\frac{v}{\sqrt{2E/m}}\right)^2 + \left(\frac{x}{\sqrt{2E/k}}\right)^2$$

$$1 = \frac{mv^2}{2E} + \frac{kx^2}{2E} = (\cos\theta)^2 + (\sin\theta)^2$$

Another example of the old "scale-a-circle" trick...

$$Let:\ (1)\ v = \sqrt{2E/m}\cos\theta, \quad and:\ (2)\ x = \sqrt{2E/k}\sin\theta \qquad def.\ (3)\ \omega = \frac{d\theta}{dt}$$

$$\sqrt{\frac{2E}{m}}\cos\theta = v = \frac{dx}{dt} = \frac{d\theta}{dt}\frac{dx}{d\theta} = \omega\frac{dx}{d\theta} = \omega\sqrt{\frac{2E}{k}}\cos\theta$$

by (1) — *by def.* (3) — *by* (2)

by def. (3) — *divide* (1) — *by* (2) *derivative*

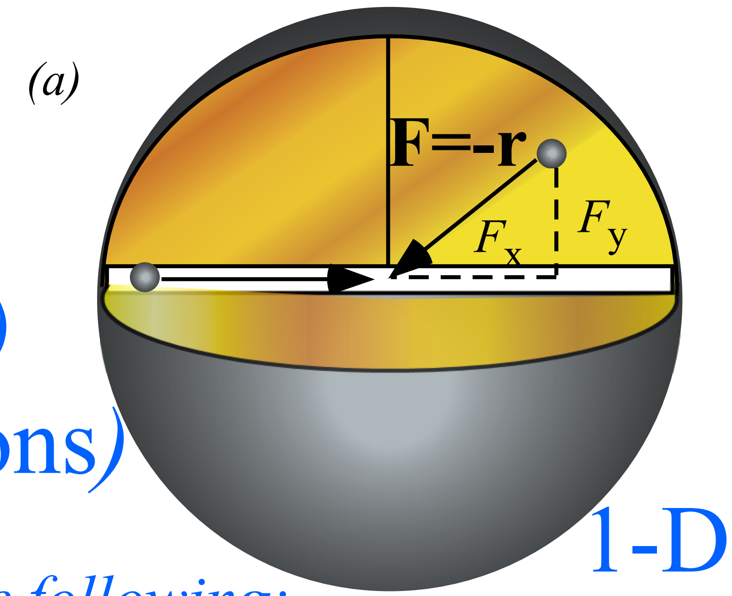
$$\omega = \frac{d\theta}{dt} = \frac{\sqrt{\frac{2E}{m}}\cos\theta}{\sqrt{\frac{2E}{k}}\cos\theta}$$

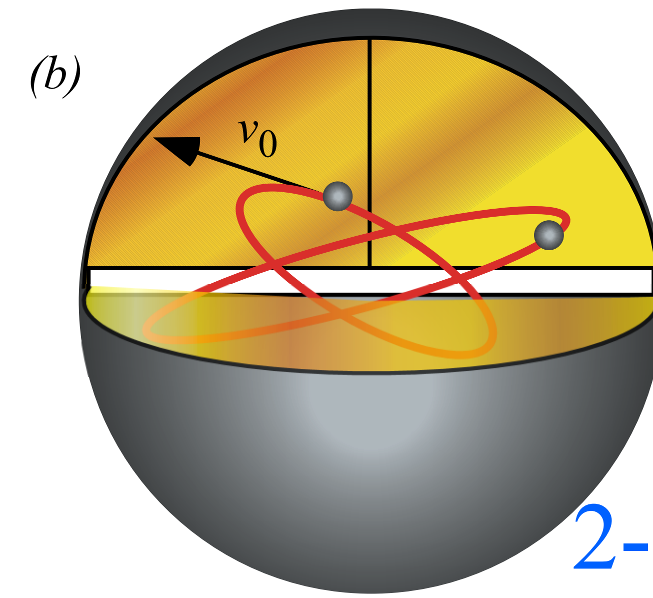
Isotropic Harmonic Oscillator phase dynamics in uniform-body

I.H.O. Force law

$F = -x$ (1-Dimension)

$\mathbf{F} = -\mathbf{r}$ (2 or 3-Dimensions)





Unit 1
Fig. 9.10

(Paths are *always* 2-D ellipses if viewed right!)

Each dimension x, y, or z obeys the following:

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by (1) — by def. (3) — by (2)

by def. (3)

$$\omega = \frac{d\theta}{dt} = \frac{\sqrt{\frac{2E}{m}}\cos\theta}{\sqrt{\frac{2E}{k}}\cos\theta} = \sqrt{\frac{k}{m}}$$

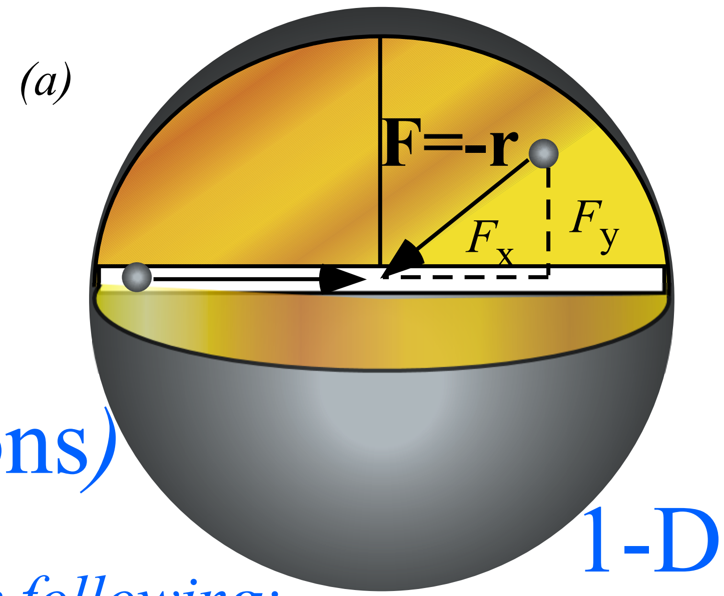
divide (1) by (2) derivative

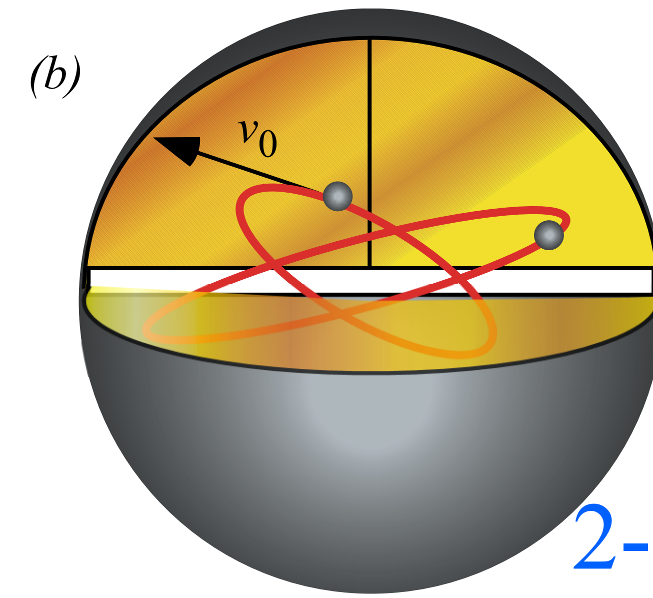
Isotropic Harmonic Oscillator phase dynamics in uniform-body

I.H.O. Force law

F =-*x* (1-Dimension)

F =-**r** (2 or 3-Dimensions)





Unit 1
Fig. 9.10

(Paths are *always* 2-D ellipses if viewed right!)

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by (1) *by def.* (3) *by* (2)

by def. (3)

$$\omega = \frac{d\theta}{dt} = \sqrt{\frac{k}{m}}$$

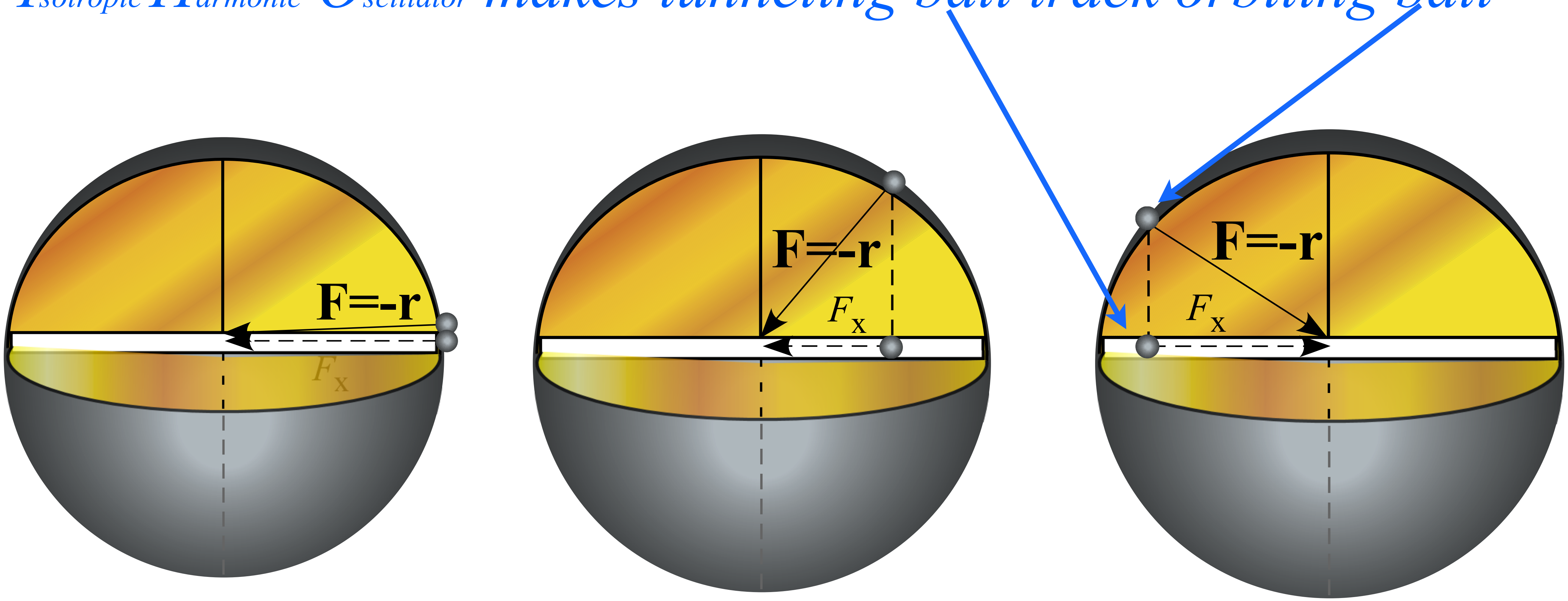
by integration given constant ω:

$$\theta = \int \omega \cdot dt = \omega \cdot t + \alpha$$

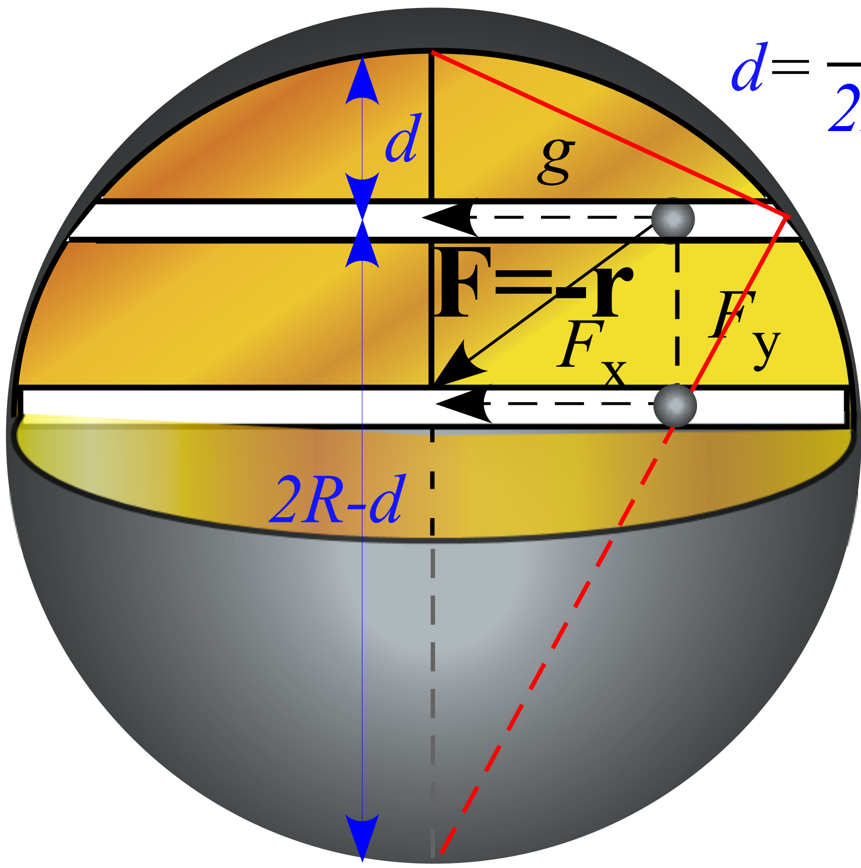
→ *Introducing 2D IHO orbits and phasor geometry*

Phasor “clock” geometry

*I*sotropic *H*armonic *O*scillator *makes tunneling ball track orbiting ball*

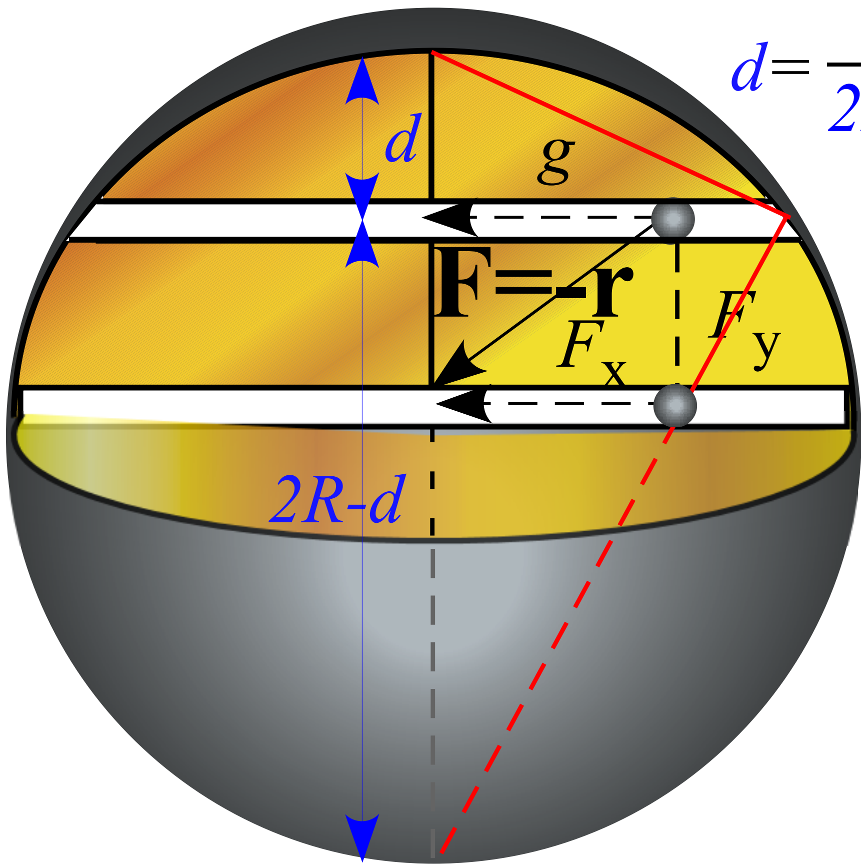


Isotropic Harmonic Oscillator makes balls in parallel tunnel track each other



$$d = \frac{g^2}{2R-d} \sim \frac{g^2}{2R}$$

$I_{sotropic}\ H_{armonic}\ O_{scillator}$ makes balls in parallel tunnels track each other...



$$d = \frac{g^2}{2R-d} \sim \frac{g^2}{2R}$$

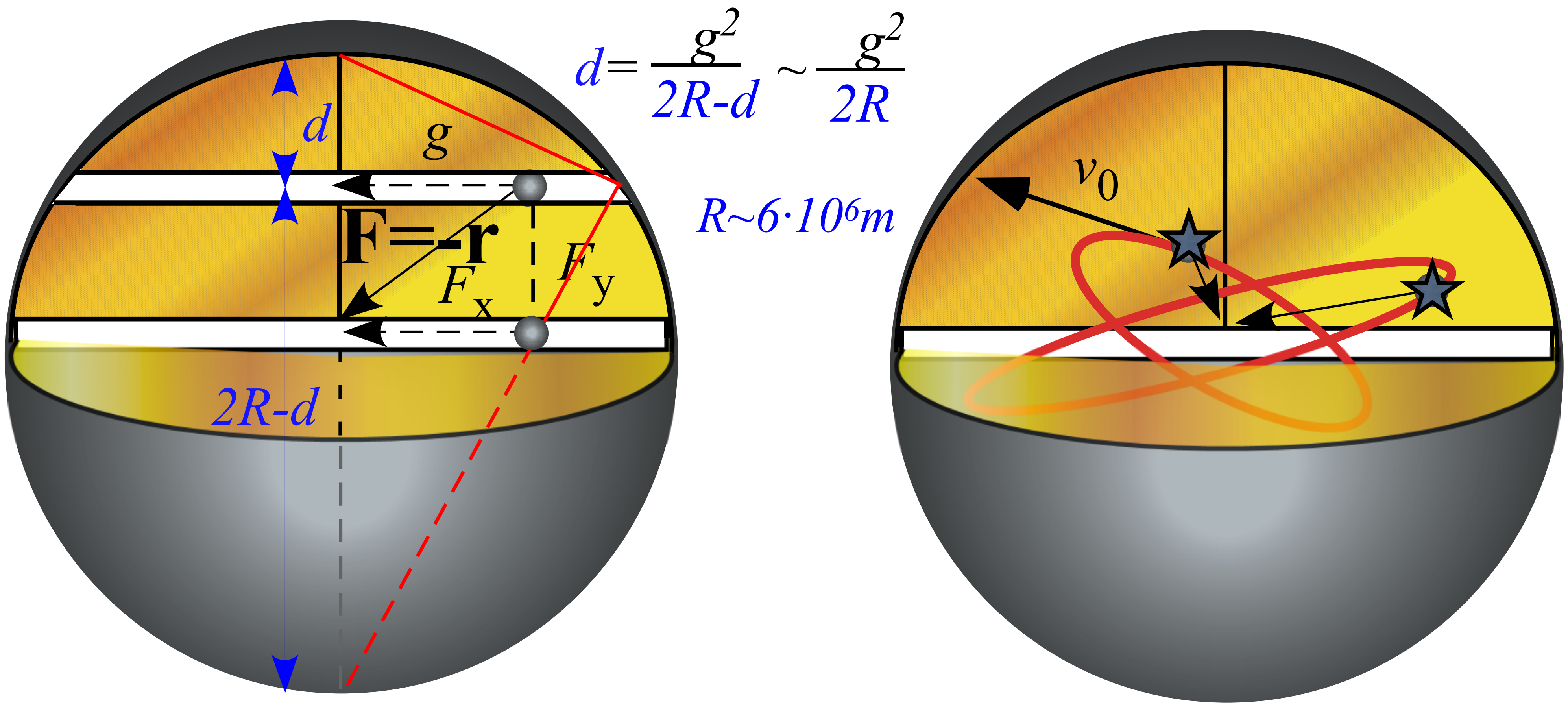
$R \sim 6 \cdot 10^6 m$

$$d \sim \frac{1}{2R}$$

...even if track length is just $g = 1m$ *so* $d \sim (1/12) micron$

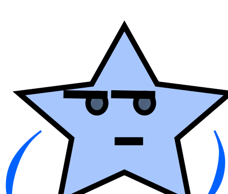
They all take about 84 minutes to go from right to left and back, again.

$I_{sotropic}$ $H_{armonic}$ $O_{scillator}$ makes balls in parallel tunnels track each other...



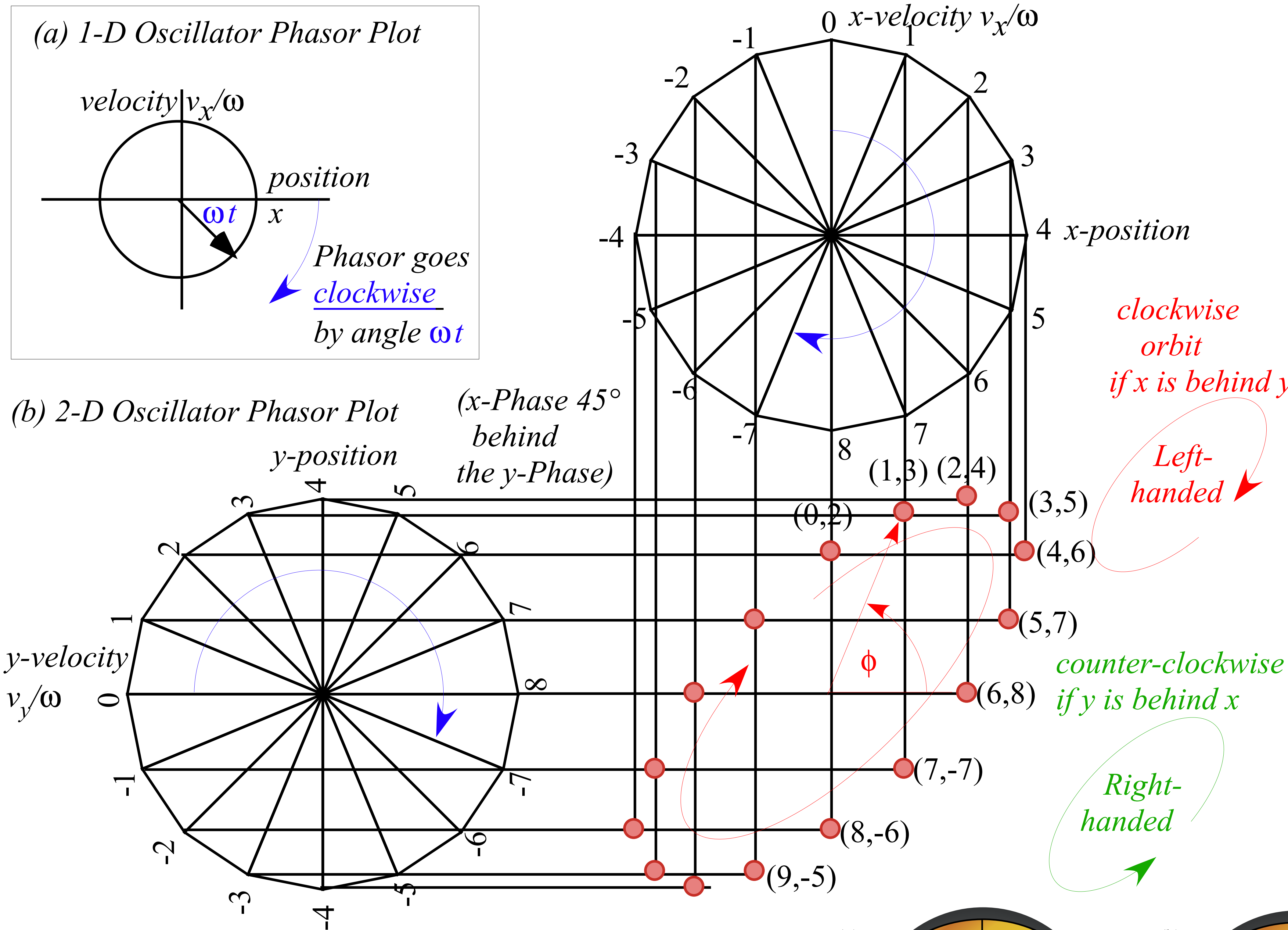
...even if track length is just $g = 1m$ *so* $d = (1/12)$*micron*

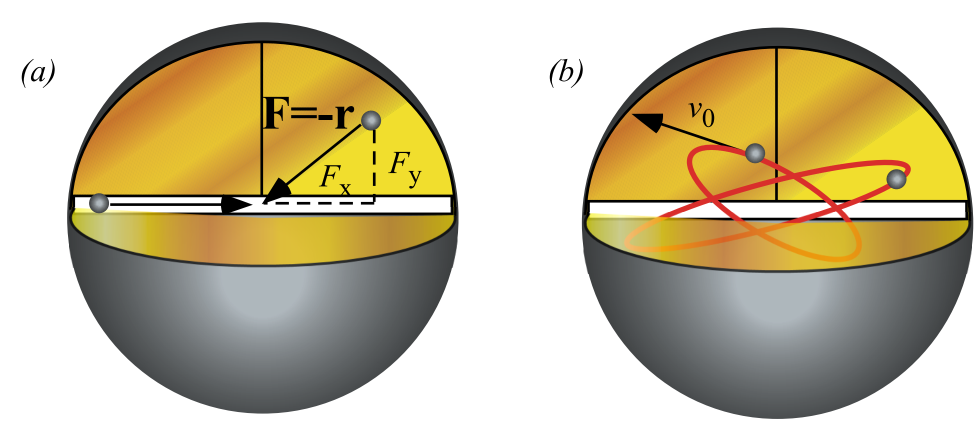
The all take about 84 minutes to go from right to left and back, again.

Most neutron starlet ( *)orbits are centered ellipses*

Isotropic Harmonic Oscillator phase dynamics in uniform-body

Unit 1
Fig. 9.10

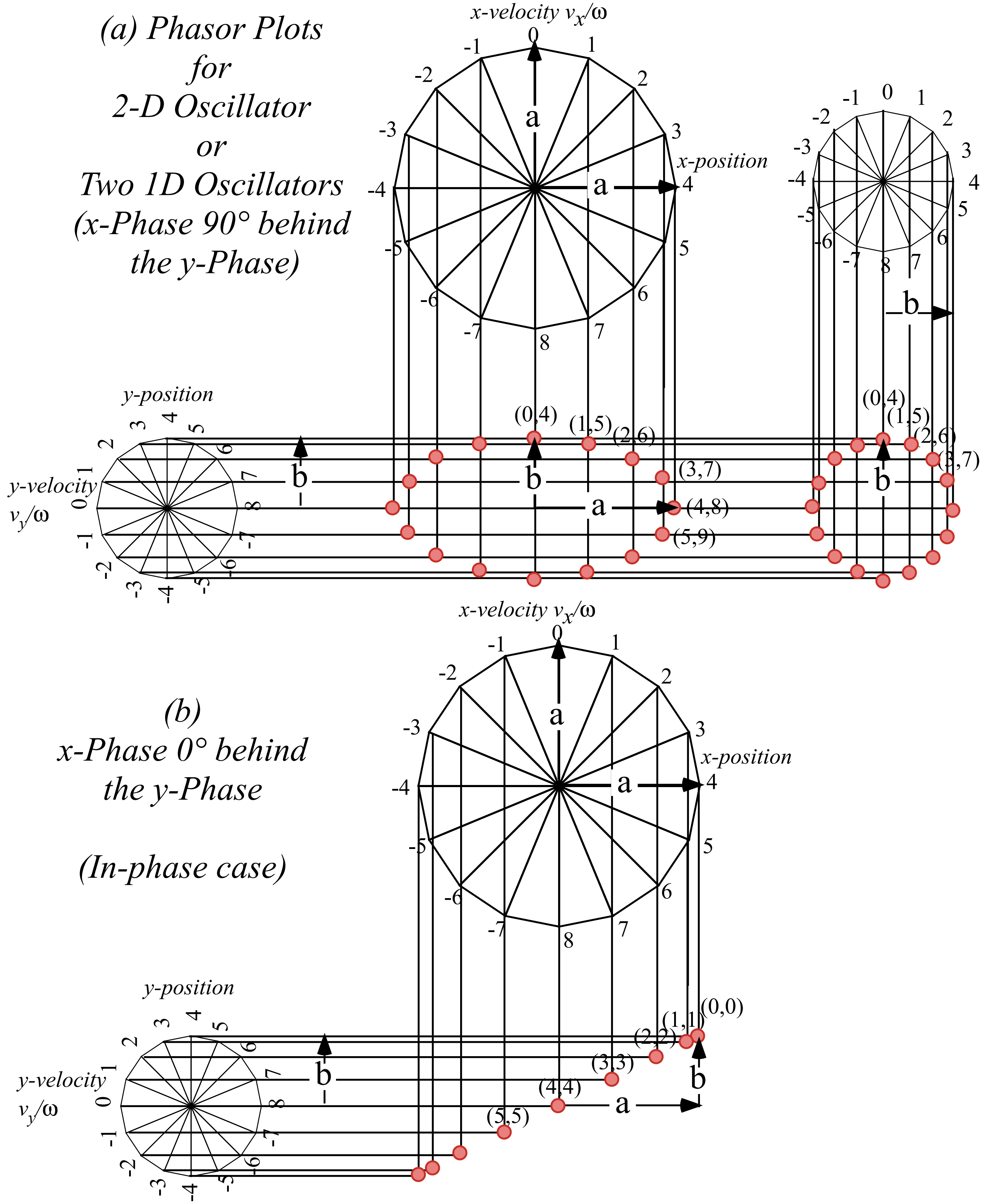




[RelaWavity web simulation - Contact ellipsometry]

Introduction to Phasors at our Pirelli Relativity Site
BoxIt web simulation - *With y-Phasor is on other side of xy plot*

Unit 1
Fig. 9.12



These are more generic examples with radius of x-phasor differing from that of the y-phasor.

RelaWavity web simulation - Contact ellipsometry *(User Mouse Input allowed for setting phasor values)*

AMOP reference links *(Updated list given on **2nd** and 3rd pages of each class presentation)*

Web Resources - front page
UAF Physics UTube channel

Quantum Theory for the Computer Age
Principles of Symmetry, Dynamics, and Spectroscopy
Classical Mechanics with a Bang!
Modern Physics and its Classical Foundations

2014 AMOP
2017 Group Theory for QM
2018 AMOP

Representaions Of Multidimensional Symmetries In Networks - harter-jmp-1973

Alternative Basis for the Theory of Complex Spectra

- Alternative_Basis_for_the_Theory_of_Complex_Spectra_I_-_harter-pra-1973
- Alternative_Basis_for_the_Theory_of_Complex_Spectra_II_-_harter-patterson-pra-1976
- Alternative_Basis_for_the_Theory_of_Complex_Spectra_III_-_patterson-harter-pra-1977

Frame Transformation Relations And Multipole Transitions In Symmetric Polyatomic Molecules - RMP-1978
Asymptotic eigensolutions of fourth and sixth rank octahedral tensor operators - Harter-Patterson-JMP-1979
Rotational energy surfaces and high- J eigenvalue structure of polyatomic molecules - Harter - Patterson - 1984
Galloping waves and their relativistic properties - ajp-1985-Harter
Rovibrational Spectral Fine Structure Of Icosahedral Molecules - Cpl 1986 (Alt Scan)

Theory of hyperfine and superfine levels in symmetric polyatomic molecules.

I) Trigonal and tetrahedral molecules: Elementary spin-1/2 cases in vibronic ground states - PRA-1979-Harter-Patterson (Alt scan)
II) Elementary cases in octahedral hexafluoride molecules - Harter-PRA-1981 (Alt scan)

Rotation–vibration spectra of icosahedral molecules.

I) Icosahedral symmetry analysis and fine structure - harter-weeks-jcp-1989 (Alt scan)
II) Icosahedral symmetry, vibrational eigenfrequencies, and normal modes of buckminsterfullerene - weeks-harter-jcp-1989 (Alt scan)
III) Half-integral angular momentum - harter-reimer-jcp-1991

Rotation-vibration scalar coupling zeta coefficients and spectroscopic band shapes of buckminsterfullerene - Weeks-Harter-CPL-1991 (Alt scan)
Nuclear spin weights and gas phase spectral structure of 12C60 and 13C60 buckminsterfullerene -Harter-Reimer-Cpl-1992 - (Alt1, Alt2 Erratum)
Gas Phase Level Structure of C60 Buckyball and Derivatives Exhibiting Broken Icosahedral Symmetry - reimer-diss-1996
Fullerene symmetry reduction and rotational level fine structure/ the Buckyball isotopomer 12C 13C59 - jcp-Reimer-Harter-1997 (HiRez)
Wave Node Dynamics and Revival Symmetry in Quantum Rotors - harter - jms - 2001
Molecular Symmetry and Dynamics - Ch32-Springer Handbooks of Atomic, Molecular, and Optical Physics - Harter-2006

Resonance and Revivals

I) QUANTUM ROTOR AND INFINITE-WELL DYNAMICS - ISMSLi2012 (Talk) OSU knowledge Bank
II) Comparing Half-integer Spin and Integer Spin - Alva-ISMS-Ohio2013-R777 (Talks)
III) Quantum Resonant Beats and Revivals in the Morse Oscillators and Rotors - (2013-Li-Diss)

Resonance and Revivals in Quantum Rotors - Comparing Half-integer Spin and Integer Spin - Alva-ISMS-Ohio2013-R777 (Talk)
Molecular Eigensolution Symmetry Analysis and Fine Structure - IJMS-harter-mitchell-2013
Quantum Revivals of Morse Oscillators and Farey-Ford Geometry - Li-Harter-cpl-2013
QTCA Unit 10 Ch 30 - 2013
AMOP Ch 0 Space-Time Symmetry - 2019

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https://modphys.hosted.uark.edu/markup/AMOP_References.html
and eventually full on Apache-SOLR *Index and search for* nuanced, whole-site content/metadata level *searching.*

AMOP reference links (Updated list given on 2nd and 3rd pages of each class presentation)

(Int.J.Mol.Sci, 14, 714(2013) p.755-774 , QTCA Unit 7 Ch. 23-26), (PSDS - Ch. 5, 7)

Int.J.Mol.Sci, 14, 714(2013), QTCA Unit 8 Ch. 23-25, QTCA Unit 9 Ch. 26, PSDS Ch. 5, PSDS Ch. 7

Intro spin ½ coupling
Unit 8 Ch. 24 p3

H atom hyperfine-B-level crossing
Unit 8 Ch. 24 p15

Hyperf. theory Ch. 24 p48.

Hyperf. theory Ch. 24 p48.
Deeper theory ends p53

Intro 2p3p coupling
Unit 8 Ch. 24 p17.

Intro LS-jj coupling
Unit 8 Ch. 24 p22.

CG coupling derived (start)
Unit 8 Ch. 24 p39.

CG coupling derived (formula)
Unit 8 Ch. 24 p44.

Lande' g-factor
Unit 8 Ch. 24 p26.

Irrep Tensor building
Unit 8 Ch. 25 p5.

Irrep Tensor Tables
Unit 8 Ch. 25 p12.

Wigner-Eckart tensor Theorem.
Unit 8 Ch. 25 p17.

Tensors Applied to d,f-levels.
Unit 8 Ch. 25 p21.

Tensors Applied to high J levels.
Unit 8 Ch. 25 p63.

Intro 3-particle coupling.
Unit 8 Ch. 25 p28.

Intro 3,4-particle Young Tableaus
GrpThLect29 p42.

Young Tableau Magic Formulae
GrpThLect29 p46-48.

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AMOP reference links *(Updated list given on 2nd and **3rd** and **4th** pages of each class presentation)*

Predrag Cvitanovic's: Birdtrack Notation, Calculations, and Simplification

Chaos_Classical_and_Quantum_-_2018-Cvitanovic-ChaosBook
Group Theory - PUP_Lucy_Day_-_Diagrammatic_notation_-_Ch4
Simplification_Rules_for_Birdtrack_Operators_-_Alcock-Zeilinger-Weigert-zeilinger-jmp-2017
Group Theory - Birdtracks_Lies_and_Exceptional_Groups_-_Cvitanovic-2011
Simplification_rules_for_birdtrack_operators-_jmp-alcock-zeilinger-2017
Birdtracks for SU(N) - 2017-Keppeler

Frank Rioux's: UMA method of vibrational induction

Quantum_Mechanics_Group_Theory_and_C60_-_Frank_Rioux_-_Department_of_Chemistry_Saint_Johns_U
Symmetry_Analysis_for_H20-_H20GrpTheory-_Rioux
Quantum_Mechanics-Group_Theory_and_C60_-_JChemEd-Rioux-1994
Group_Theory_Problems-_Rioux-_SymmetryProblemsX
Comment_on_the_Vibrational_Analysis_for_C60_and_Other_Fullerenes_Rioux-RSP

Supplemental AMOP Techniques & Experiment

Many Correlation Tables are Molien Sequences - Klee (Draft 2016)
High-resolution_spectroscopy_and_global_analysis_of_CF4_rovibrational_bands_to_model_its_atmospheric_absorption-_carlos-Boudon-jqsrt-2017
Symmetry and Chirality - Continuous_Measures_-_Avnir

*

Special Topics & Colloquial References

r-process_nucleosynthesis_from_matter_ejected_in_binary_neutron_star_mergers-PhysRevD-Bovard-2017

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