Prof. Fred Olness: SMU Physics QuarkNet 2013

Interesting Books:

Flatland : A Romance of Many Dimensions

A classic--a must read. There are many editions, but Dover is $2.00 if you can still find it in print. ISBN: 048627263X Paperback: 96 pages.

There are more expensive editions, or you can download in free from Project Gutenberg http://www.gutenberg.net/   Specifically, http://www.gutenberg.net/etext/201

The Shape of Space : How to Visualize Surfaces and Three-Dimensional Manifolds,

by Jeffrey R. Weeks; Marcel Dekker; ISBN: 082477437X.

A wonderful book that helps us visualize higher dimensional curved spaces and nontrivial topologies.

Mr Tompkins in Paperback,

by George Gamow; Cambridge Univ Pr. ISBN: 0521447712.

A classic! Provides an intuitive introduction to relativity, cosmology, quantum mechanics, and more.

One Two Three...Infinity: Facts and Speculations of Science

by George Gamow; Dover Pub; ISBN: 0486256642.

From the micro to the macro.

The First Three Minutes : A Modern View of the Origin of the Universe.

By Steven Weinberg, Basic Books; ISBN: 0465024378.

A non-technical introduction to cosmology and the origins of the universe.

The Ideas of Particle Physics

by G. D. Coughlan, J. E. Dodd, Cambridge Univ Pr (Short); ISBN: 0521386772.

Contains wonderful explanations of basic particle physics phenomena with simple, non-technical explanations.

The Evolution of Physics” Einstein, Albert and Infeld, Leopold.

ISBN: 0-671-20156-5 A non-mathematical treatment of physics from classical through relativity and quantum.   Excellent intuitive insights and a great read.

Websites:

Shape of Space:

http://www.youtube.com/watch?v=Uzd484Mvm2k
http://www.geometrygames.org/SoS/

Mechanical Universe And Beyond

http://www.learner.org/resources/series42.html

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Special Relativity

Fred Olness
SMU 2001
Quark Net

Einstein Postulates:

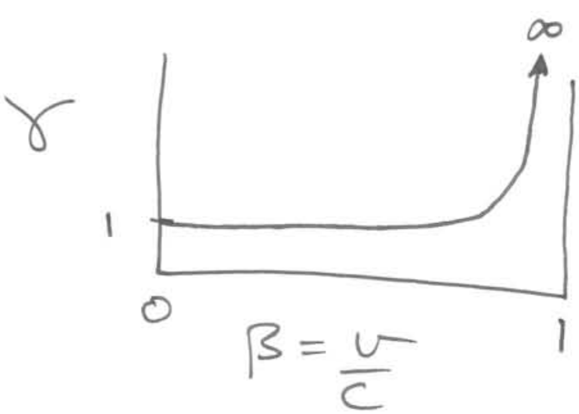
- Speed of light is constant c
- All Frames are equivalent

Consequences:

- Moving Clocks Run SLOW
- Moving Rulers are Short

Both by Factor γ

$$\beta = \frac{v}{c} \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \sqrt{1-\frac{1}{\gamma^2}}$$



Adding Velocities w/ Relativity

"... It's not just a good idea, it's the law."

Old Fashioned Way: (Galilean Tx)

$$v_{TOT} = v_1 + v_2 = 0.9c + 0.9c$$

$$v_{TOT} = 1.8c$$

Oooops!!! Faster than Light

New, Improved Way: (Lorentz Tx)

$$v_{TOT} = \frac{v_1 + v_2}{1 + \frac{v_1 v_2}{c^2}} = \frac{0.9c + 0.9c}{1 + (0.9)(0.9)} = \frac{1.80}{1.81} c$$

$$v_{TOT} = \frac{1.80}{1.81} c = 0.995c$$

OK!!! **Not** Faster than light!!!

Atmospheric Muons

Q: How can muons (μ) created in upper atmosphere reach surface of earth?

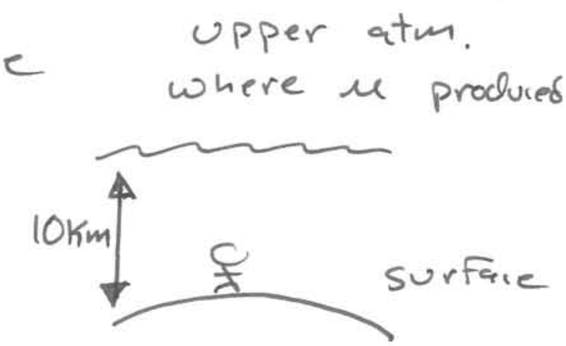
Lifetime $\tau = 2\mu s = 2\times10^{-6}\,s$

Speed $v \cong c = 3\times10^{8}\,m/s$

distance $x = vt \cong ct = (3\times10^{8}\,\frac{m}{s})(2\times10^{-6}\,s)$

$x \cong 600\,m = 0.6\,Km$

Suppose: height of atmosphere is about $\sim 10\,Km$ (I'm making up simple numbers.)



Then: muons won't reach surface without relativity.

Suppose $E \cong 2000\,MeV = 2\,GeV$

$mc^2 = 105\,MeV$

$$\gamma = \frac{E}{mc^2} \cong \frac{2000}{105} \cong 20$$

Q: Will the muon make it with relativity?

Part #1 In the Earth's Reference Frame:

The muon's clock runs slow by γ.

- with <u>NO</u> relativity, muon can travel 0.6 Km
- with relativity, muon can travel

$$\text{distance} = \gamma \cdot (0.6\,\text{Km}) = (20)(0.6\,\text{Km})$$

$$= 12\,\text{Km}$$

Conclusion: the muon <u>will</u> make it!!!

Part #2 In the muon's reference frame:

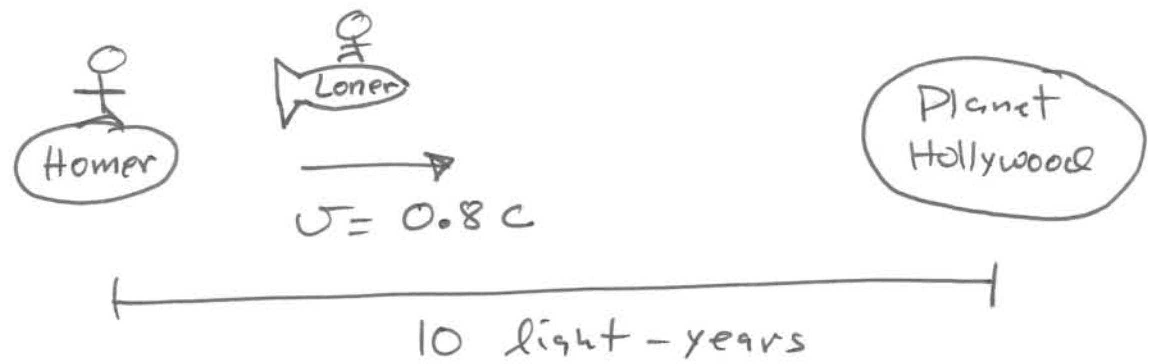
The thickness of the atmosphere is contracted by γ.

- with <u>NO</u> relativity, muon can only travel 0.6 Km through 10 Km of atmosphere.
- with relativity, thickness of atmosphere is not 10 Km but $\frac{10\,\text{Km}}{\gamma} = \frac{10\,\text{Km}}{20} = \frac{1}{2}\,\text{Km}$ $= 0.5\,\text{Km}$. Since muon can go 0.6 Km the muon <u>will</u> make it!!!

Punch-line For theory to be consistent, BOTH answers must agree!!!

The Twin Paradox:

Homer and Loner are twins.



$$\beta = \frac{v}{c} = 0.8 = \frac{4}{5}$$

$$\beta = \sqrt{1 - \frac{1}{\gamma^2}}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{5}{3}$$

Q: How long will it take Loner to make a round trip?

Part #1 Compute from Earth's reference frame.

$$x = v t \qquad t = \frac{x}{v} = \frac{x/c}{v/c} = \frac{20 \text{ light-years}}{4/5} = 25$$

$t = 25$ years for round trip

Part #2 Compute in Loner's frame.

Note: distance is <u>short</u> by γ

$$\therefore \frac{20 \text{ light-years}}{\gamma} = \frac{20}{5/3} = 12 \text{ light-years}$$

$$x = vt \qquad t = \frac{x}{v} = \frac{x/c}{v/c} = \frac{12}{4/5} = 15 \text{ years}$$

Conclusion: Homer ages 25 years
Loner ages 15 years

Cross-Check In Earth frame, work out time that passes on Loner's clock.

Observe: Loner's clock runs slow by γ.

Loner's trip takes 25 years

But Loner's clock ticks off $\frac{25}{\gamma}$ years

$$\frac{25}{\gamma} = \frac{25}{5/3} = 15 \text{ years}$$

<u>This is consistent!!!</u>

Misc. Topics: Friday 8 June 2001

F. Olness
SMU

Einstein Equivalence Principle:

Earth Ref Frame $\equiv$ Accelerating Space Ship

$g = 9.8\,\frac{m}{s^2}$

$a = g$

Result:

① Gravitational mass $\equiv$ inertial mass

$$F = \frac{G M m}{r^2} = m g \equiv m a$$

② Light bends in gravitational.

③ Mass $\Rightarrow$ grav. Field

grav. Field $\Rightarrow$ curved space

∴ $G = T - ?$

- G: Curvature of Space
- T: Stress-Energy Tensor
- $?$: Cosmological Constant

Test of Bending Light.

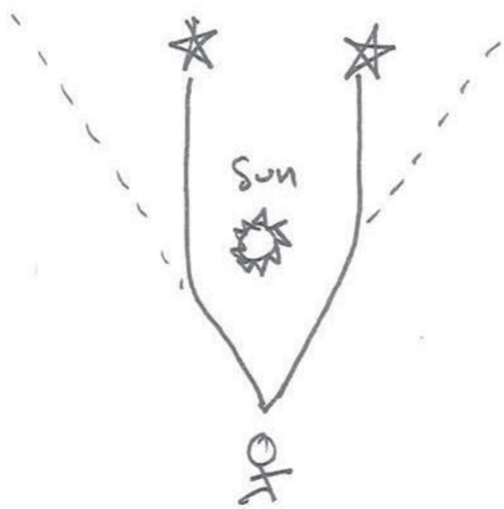
Observe 2 stars:

No sun:

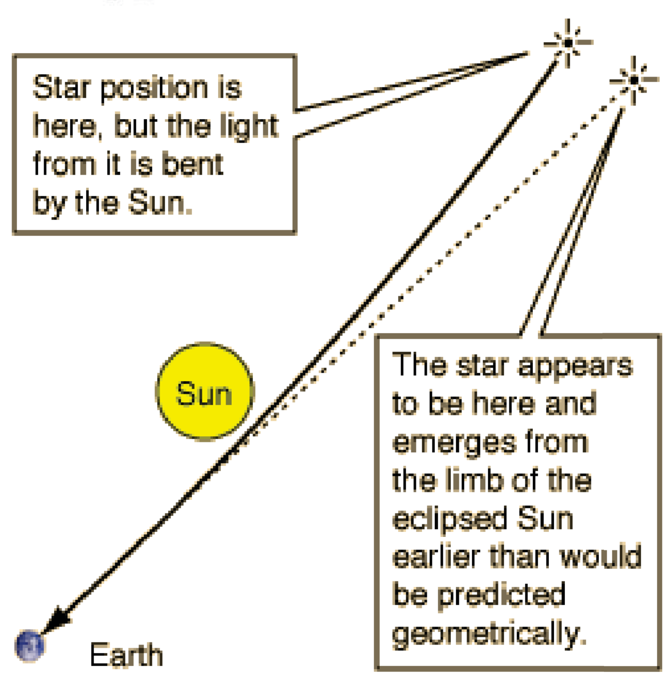
$\theta = 20°$

With sun

$\theta = 30°$



Bending of light makes stars appear further apart.



Einsteins Equation

$$G = 8\pi T - \Lambda$$

- G: Einstein Tensor (Curvature of space)
- T: Stress-Energy Tensor (mass)
- Λ: Cosmological Constant

IF If $\Lambda = 0$, then if the universe has no mass ($T = 0$) then the curvature $= 0$ ($G = 0$)

But It appears $\Lambda \neq 0$, therefore empty space time is <u>NOT</u> Flat.

Historical Note Einstein introduced Λ to obtain "Static" Universe solution. ~ 10 years later, it was discovered that the universe was expanding.

"... my greatest blunder!"

Field Trip to Flat Land

Q: What type of world do we live in?

A: Define Euler Number χ

$\chi = F - E + V$ Constant for a given surface

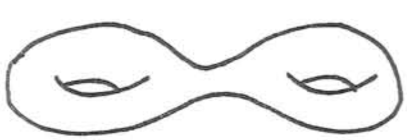
$F = 4$
$E = 6$
$V = 4$

$\chi = 4 - 6 + 4 = 2$

\# holes

Sphere  $\chi = 2$ $G = 0$

Torus (Doughnut)  $\chi = 0$ Flat $G = 1$

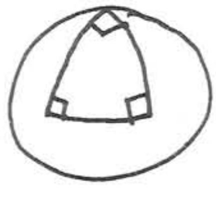
 $\chi = -2$ $G = 2$

 $\chi = -4$ $G = 3$

$\vdots$

$$\boxed{\chi = 2 - 2G}$$

On Uniform Sphere, $\Delta \neq 180°$



$$\theta_1 + \theta_2 + \theta_3 = 270°$$

In general, $$\sum_{i=1}^{3} \theta_i = \pi + 2\pi \left(\frac{A}{4\pi R^2} \right)$$

$A = 0$, $\Sigma \theta = \pi = 180°$

$A = 4\pi R^2$, $\Sigma \theta = 3\pi = 540°$

Gauss - Bonnet Theorem:

$$\int K \, dA = 2\pi \chi$$

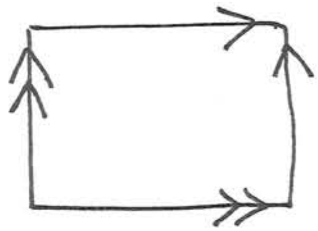
For sphere: $K \to \frac{1}{R^2}$, $\int dA \to 4\pi R^2$, $\chi \to 2$

For Torus: $K = 0$, $\chi = 0$

Upshot: this relates an intrinsic / Local quantity ($\int K dA$) to a extrinsic global (χ) quantity.

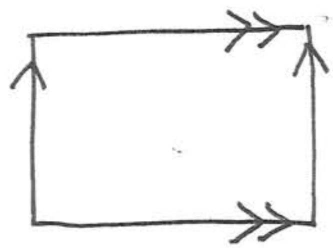
Simple 2-D Surfaces

sphere

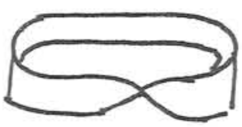


$\chi = 2$ $\quad K = \frac{1}{R^2}$

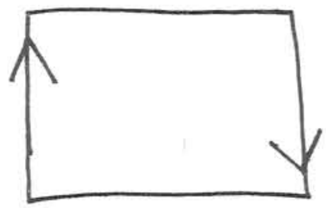
Torus



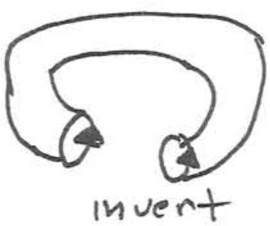
$\chi = 0$ $\quad K = 0$



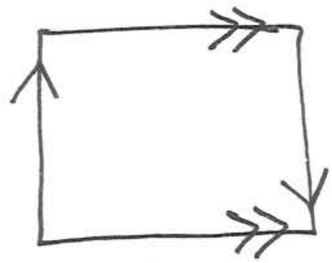
Mobius Strip



Non-orientable



Klein Bottle



Exercise: Play Tic-Tac-Toe on the above

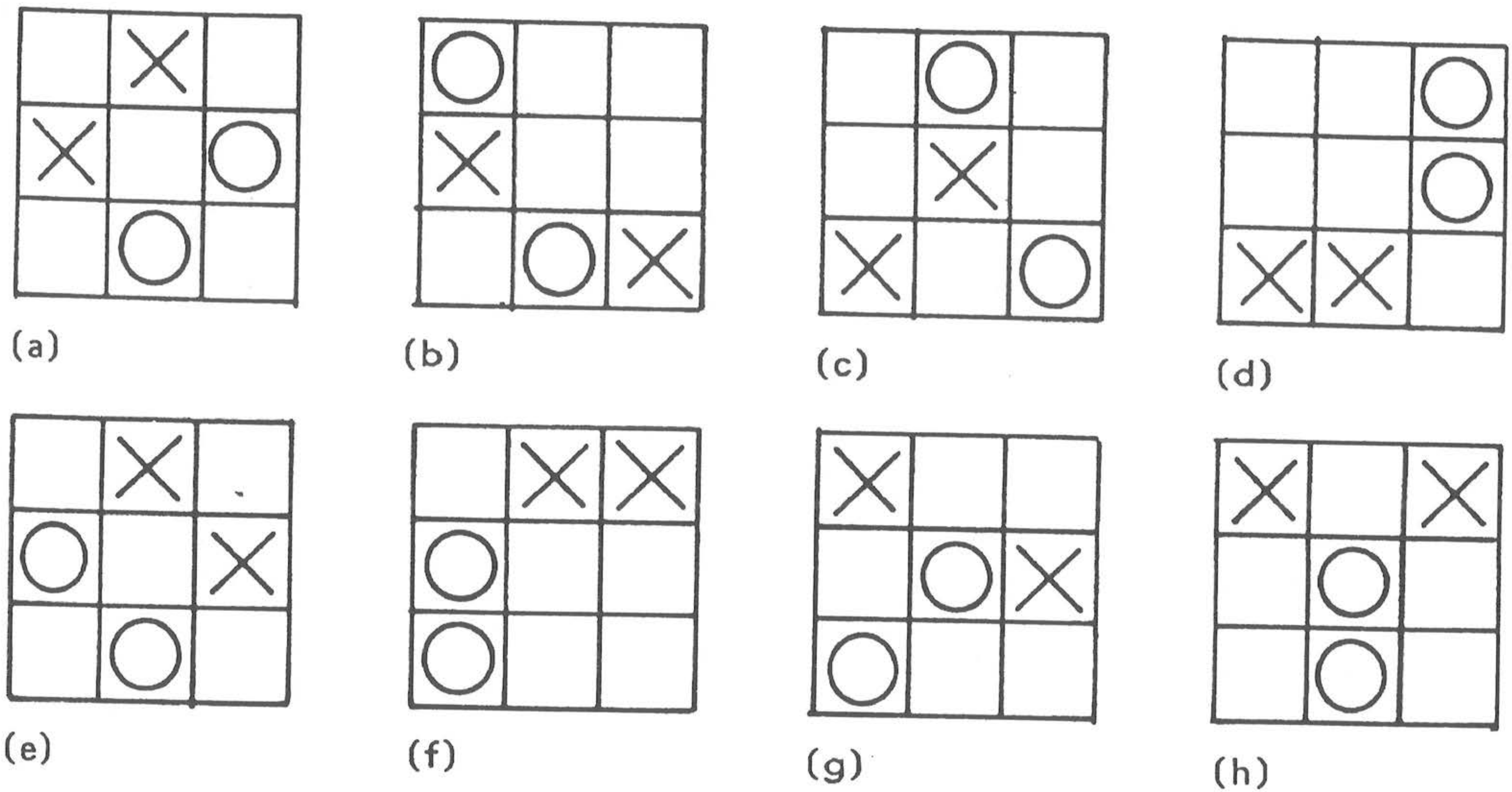


Figure 2.5: Which of these positions are equivalent in torus tic-tac-toe?

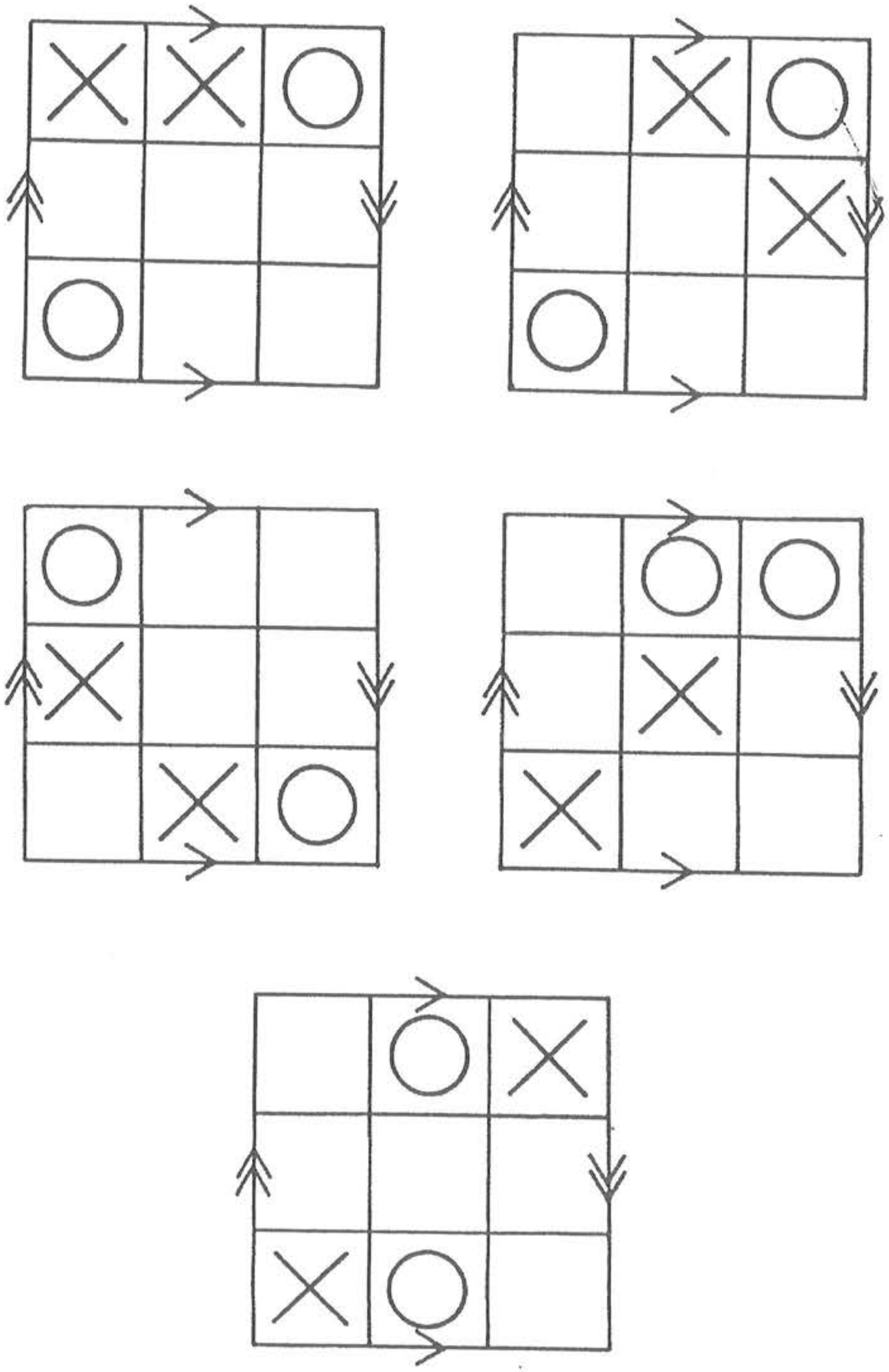


Figure 4.7: Find X's best move in each game.

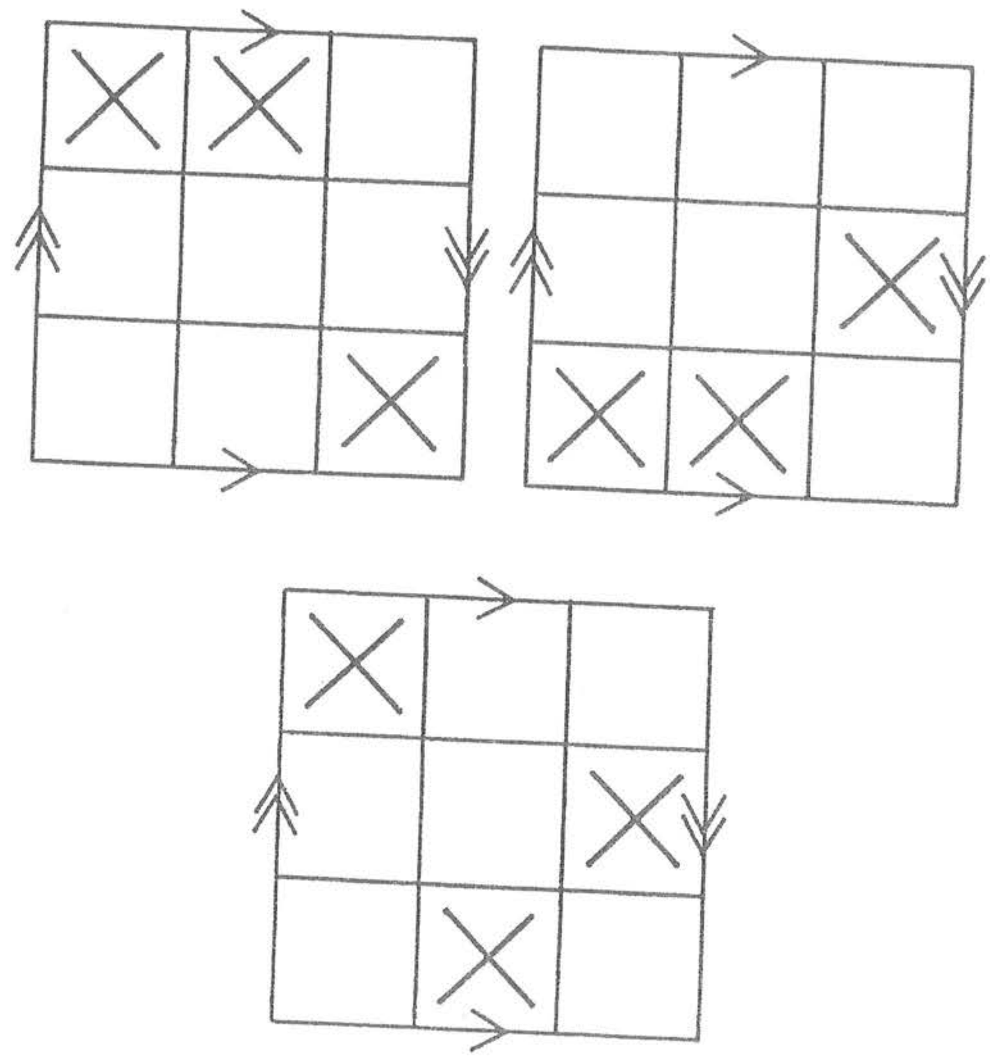


Figure 4.5: Which of these are winning positions in Klein bottle tic-tac-toe?