The Adventures of
ARCHIBALD HIGGINS

THE BLACK HOLE

Jean-Pierre Petit

The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries , within the context of schools or universities or associations whose aims would be the same as the association , provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.

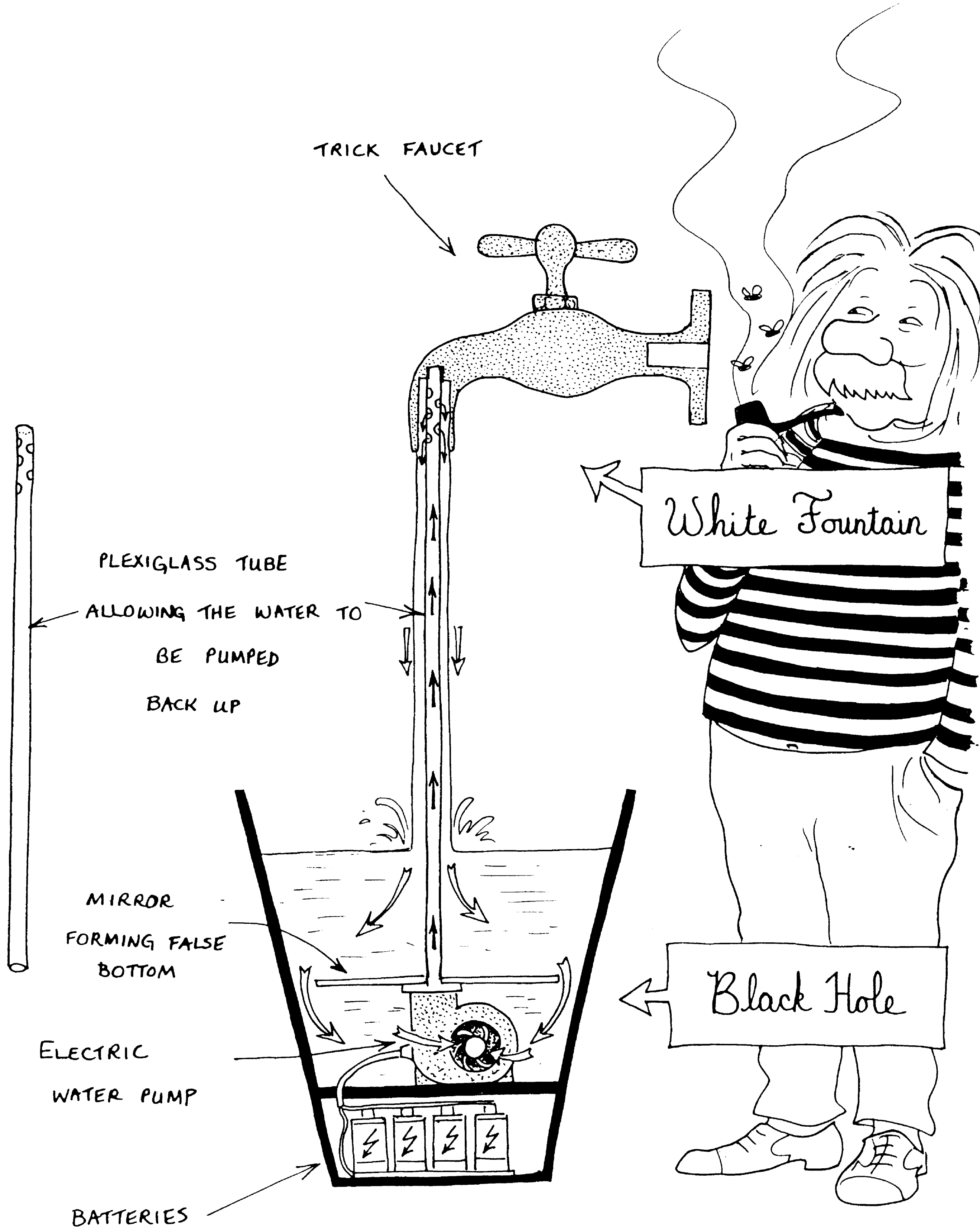
Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be "bilingual" in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

The association can be contacted on the following internet site:

http://savoir-sans-frontieres.com

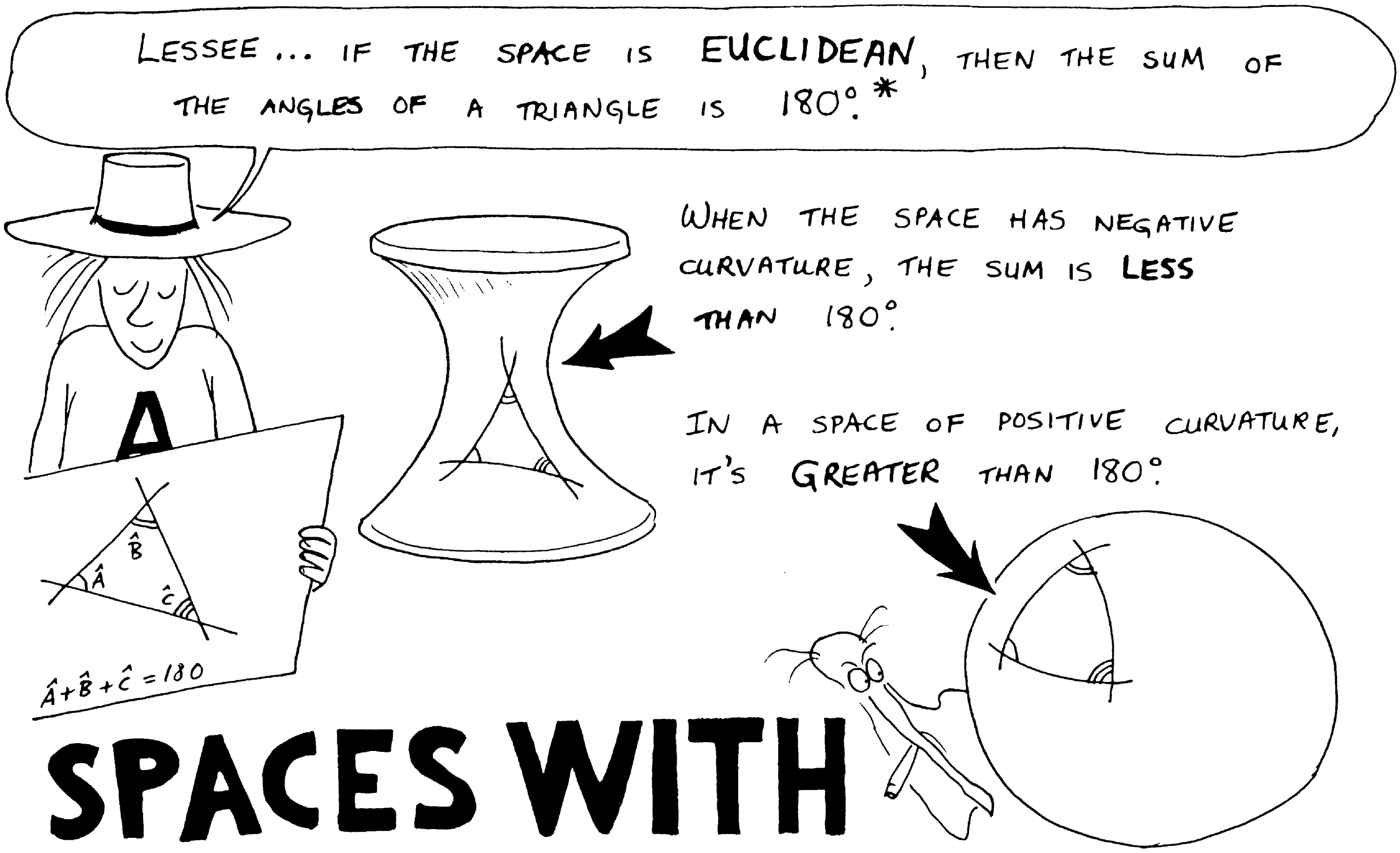

THE FAUCET'S FLOATING IN MID-AIR — SO WHERE DOES THE WATER COME FROM?
HMMM...
FOR THAT MATTER — WHERE DOES IT GO TO? THE LEVEL IN THE BUCKET NEVER CHANGES.
IT KEEPS FLOWING, ALL THE SAME.


TRICK FAUCET
White Fountain
PLEXIGLASS TUBE
ALLOWING THE WATER TO
BE PUMPED
BACK UP
MIRROR
FORMING FALSE
BOTTOM
Black Hole
ELECTRIC
WATER PUMP
BATTERIES

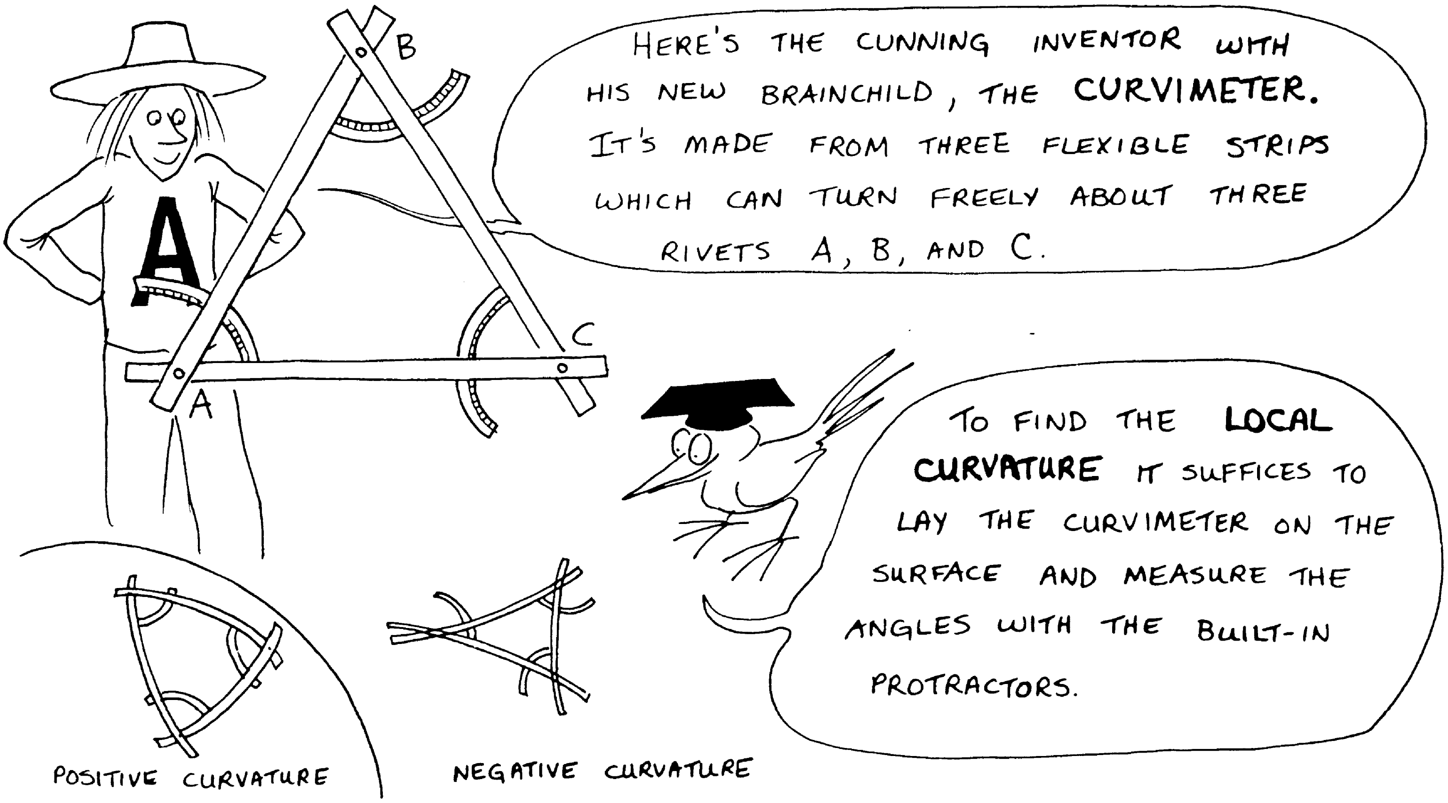

MR. ALBERT! WHAT ARE YOU DOING?
HAF' A SEAT, ARCHIBALD.
WHAT'S THIS?
COSMOL, ARCHIBALD: DER COSMOL... DAT POINTS DER WAY.
THE WAY? WHAT WAY? I DON'T UNDERSTAND.
UNDERSTAND? OH, JA, UNNERSTAN'...
EVERYONE SAYS YOU HAF' TO THINK LOGICALLY ... DAT'S GARBAGE!
... GARBAGE...
ONLY... COSMOL... CAN POINT DER WAY...
THE WAY? OH, THAT WAY! WAY OUT...


MR. ALBERT?
SOPHIE?
HUM...
THESE CLOUDS AGAIN...
ONCE MORE, ARCHIE SETS OUT TO EXPLORE THE WORLD OF MISTS.

A SURFACE IS A **2-DIMENSIONAL SPACE.** THAT IS, YOU NEED **TWO** NUMBERS — TWO COORDINATES — TO SPECIFY THE POSITION OF A POINT.



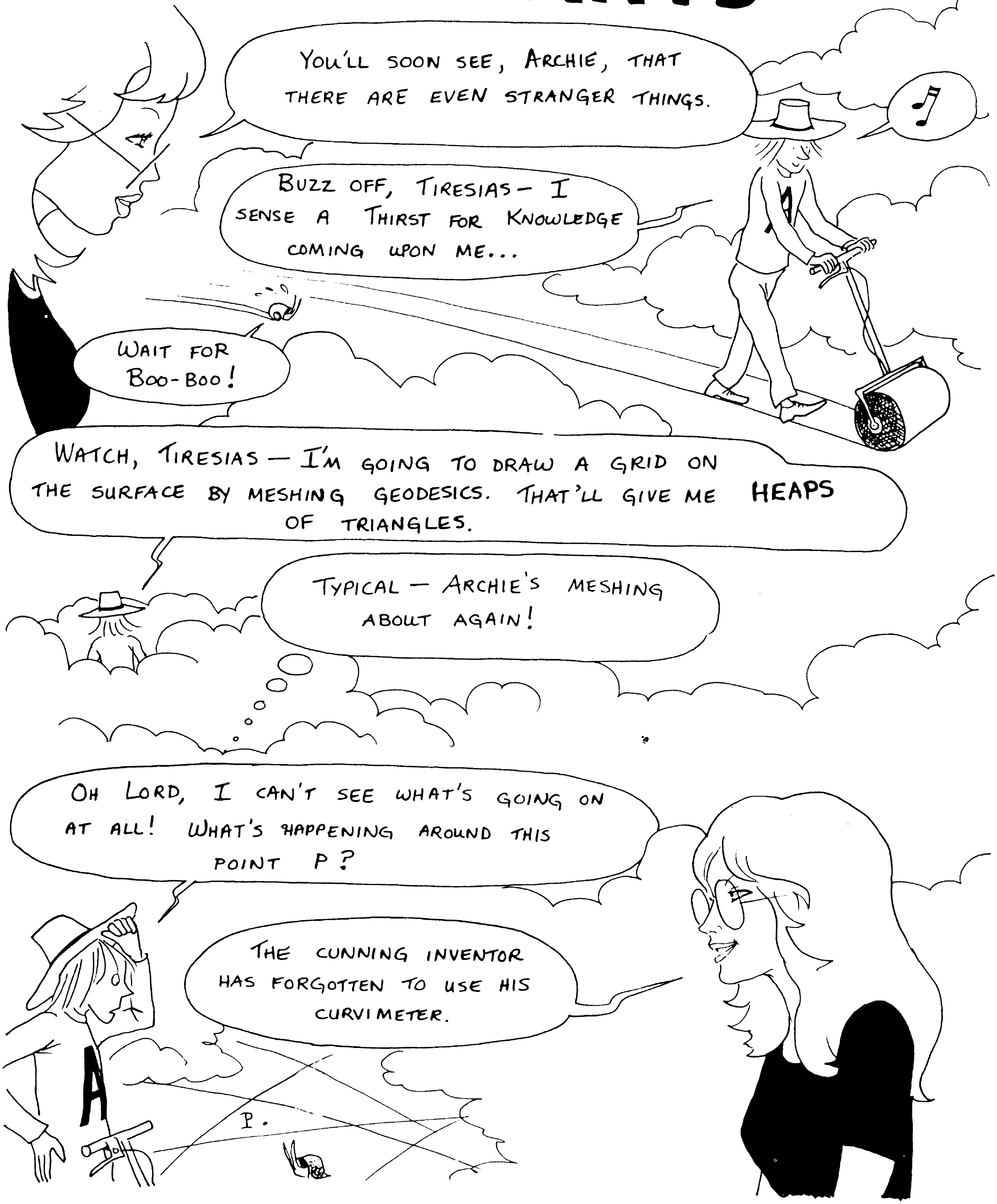
SPACES WITH VARIABLE CURVATURE



(*) FOR FURTHER DETAILS, SEE HERE'S LOOKING AT EUCLID IN THE SAME SERIES.

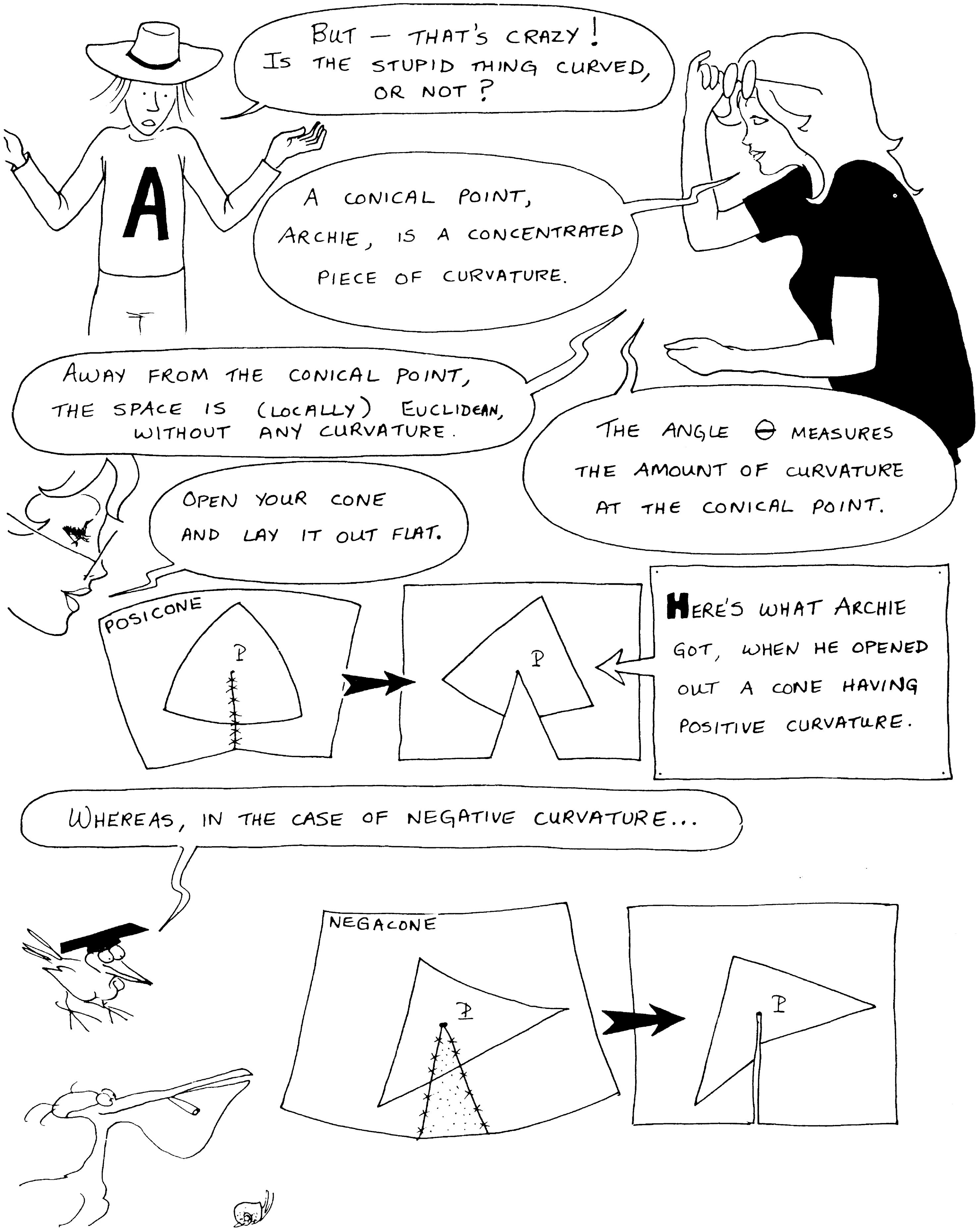
THIS BUMP IN THE PLANE IS MADE FROM A CENTRAL REGION OF POSITIVE CURVATURE, SURROUNDED BY A REGION OF NEGATIVE CURVATURE.

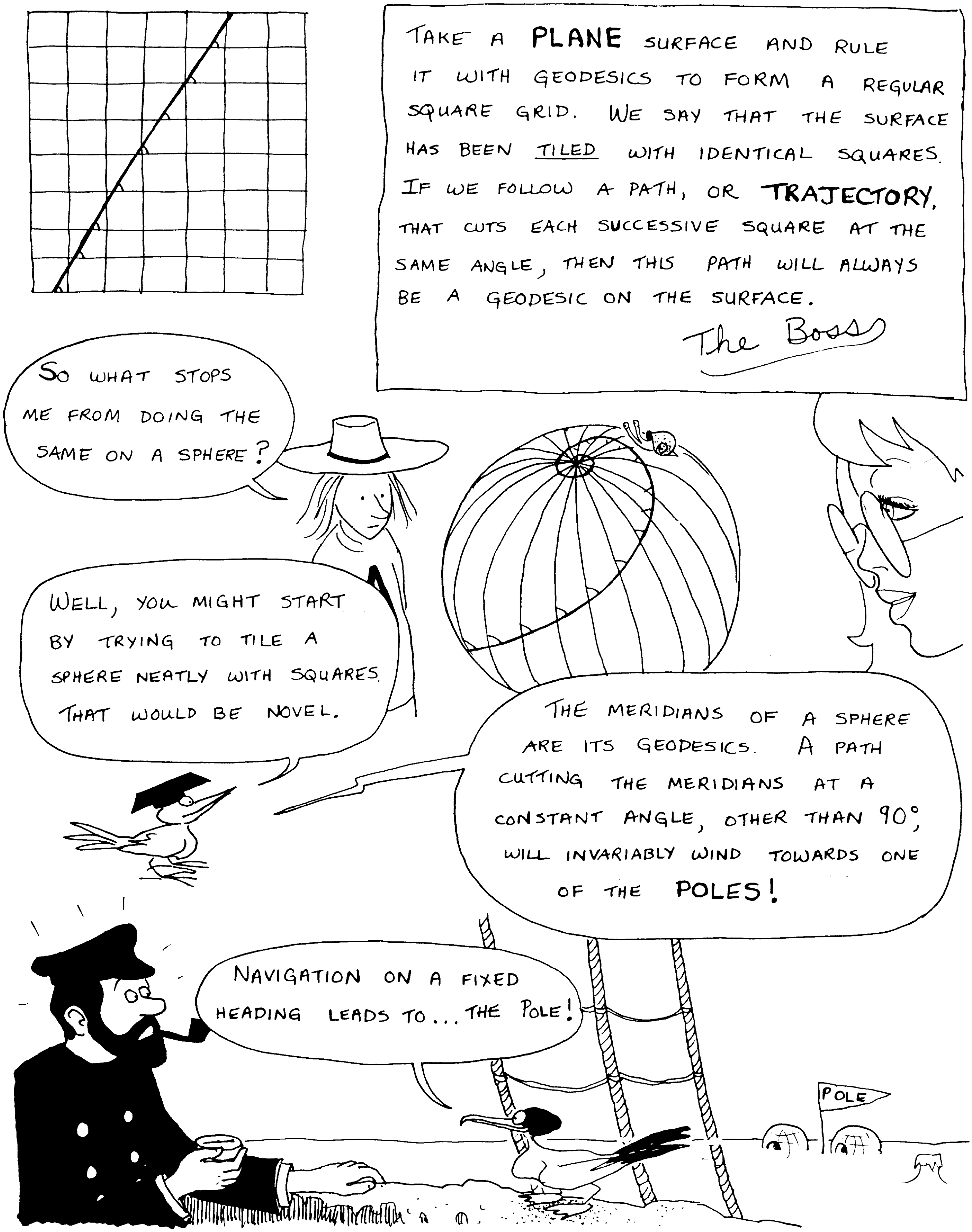
CONICAL POINTS

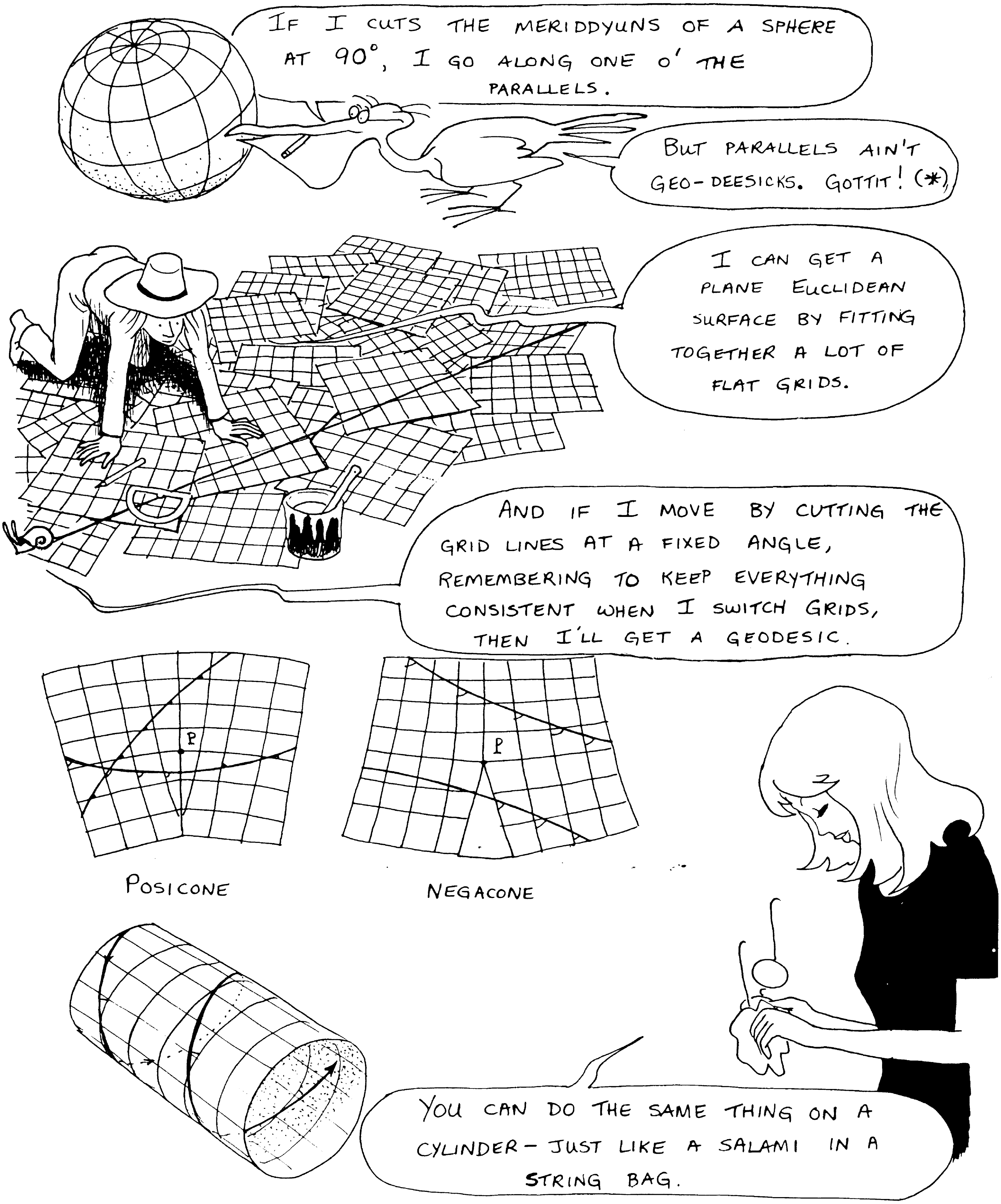



HEY, SOPHIE — WHAT'S GOING ON? IF THE CURVIMETER'S TRIANGLE DOESN'T CONTAIN THE POINT P, IT SAYS THE CURVATURE IS ZERO.
P
BUT IF P IS INSIDE THE TRIANGLE, THEN THE SPACE IS CURVED!
P
IT'S A CONICAL POINT. LOOK — SUPPOSE I TAKE A PLANE, CUT OUT A SECTOR WITH ANGLE θ, AND JOIN IT UP AGAIN.
PLANE
θ
A
B
P
C
$\hat{A}+\hat{B}+\hat{C}=180°+\theta$
I GET A KIND OF CONE, WHICH WE'LL CALL A POSICONE.
YOU CAN TEST IT OUT WITH A PIECE OF CARDBOARD. A ROLL OF STICKY TAPE WILL HELP YOU FIND GEODESICS EASILY.


OH, I SEE! IF MY TRIANGLE CONTAINS THE TIP OF A CONE THEN THE SUM OF THE ANGLES IS ALWAYS GREATER THAN 180°.
P
θ
P
θ
HOLD YOUR HORSES! IT'S NOT THAT SIMPLE! SUPPOSE INSTEAD I SLIT THE PLANE AND ADD A SECTOR WITH ANGLE θ.
DON' TELL ME— YER GETS A BLINKIN' NEGACONE.
P
THIS TIME, IF THE TRIANGLE CONTAINS THE POINT P, THE ANGLE-SUM WILL BE 180° − θ, SMALLER THAN 180°.
P
BUT IF THE POINT IS OUTSIDE THE TRIANGLE, THE SUM IS 180° AGAIN.
THIS PROPERTY OF CONES IS INDEPENDENT OF THE SIZE OF THE TRIANGLE: YOU GET THE SAME RESULT WHETHER IT'S LARGE OR SMALL.

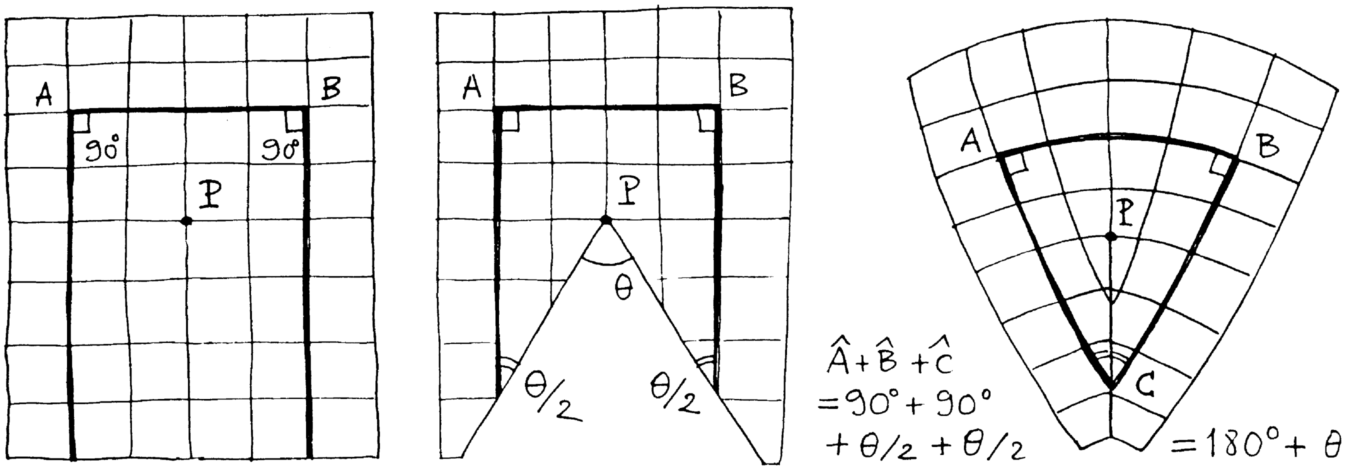

BUT — THAT'S CRAZY! IS THE STUPID THING CURVED, OR NOT?
A CONICAL POINT, ARCHIE, IS A CONCENTRATED PIECE OF CURVATURE.
AWAY FROM THE CONICAL POINT, THE SPACE IS (LOCALLY) EUCLIDEAN, WITHOUT ANY CURVATURE.
THE ANGLE θ MEASURES THE AMOUNT OF CURVATURE AT THE CONICAL POINT.
OPEN YOUR CONE AND LAY IT OUT FLAT.
POSICONE
P
P
HERE'S WHAT ARCHIE GOT, WHEN HE OPENED OUT A CONE HAVING POSITIVE CURVATURE.
WHEREAS, IN THE CASE OF NEGATIVE CURVATURE...
NEGACONE
P
P


TAKE A PLANE SURFACE AND RULE IT WITH GEODESICS TO FORM A REGULAR SQUARE GRID. WE SAY THAT THE SURFACE HAS BEEN TILED WITH IDENTICAL SQUARES. IF WE FOLLOW A PATH, OR TRAJECTORY, THAT CUTS EACH SUCCESSIVE SQUARE AT THE SAME ANGLE, THEN THIS PATH WILL ALWAYS BE A GEODESIC ON THE SURFACE.
The Boss
SO WHAT STOPS ME FROM DOING THE SAME ON A SPHERE?
WELL, YOU MIGHT START BY TRYING TO TILE A SPHERE NEATLY WITH SQUARES. THAT WOULD BE NOVEL.
THE MERIDIANS OF A SPHERE ARE ITS GEODESICS. A PATH CUTTING THE MERIDIANS AT A CONSTANT ANGLE, OTHER THAN 90°, WILL INVARIABLY WIND TOWARDS ONE OF THE POLES!
NAVIGATION ON A FIXED HEADING LEADS TO... THE POLE!
POLE



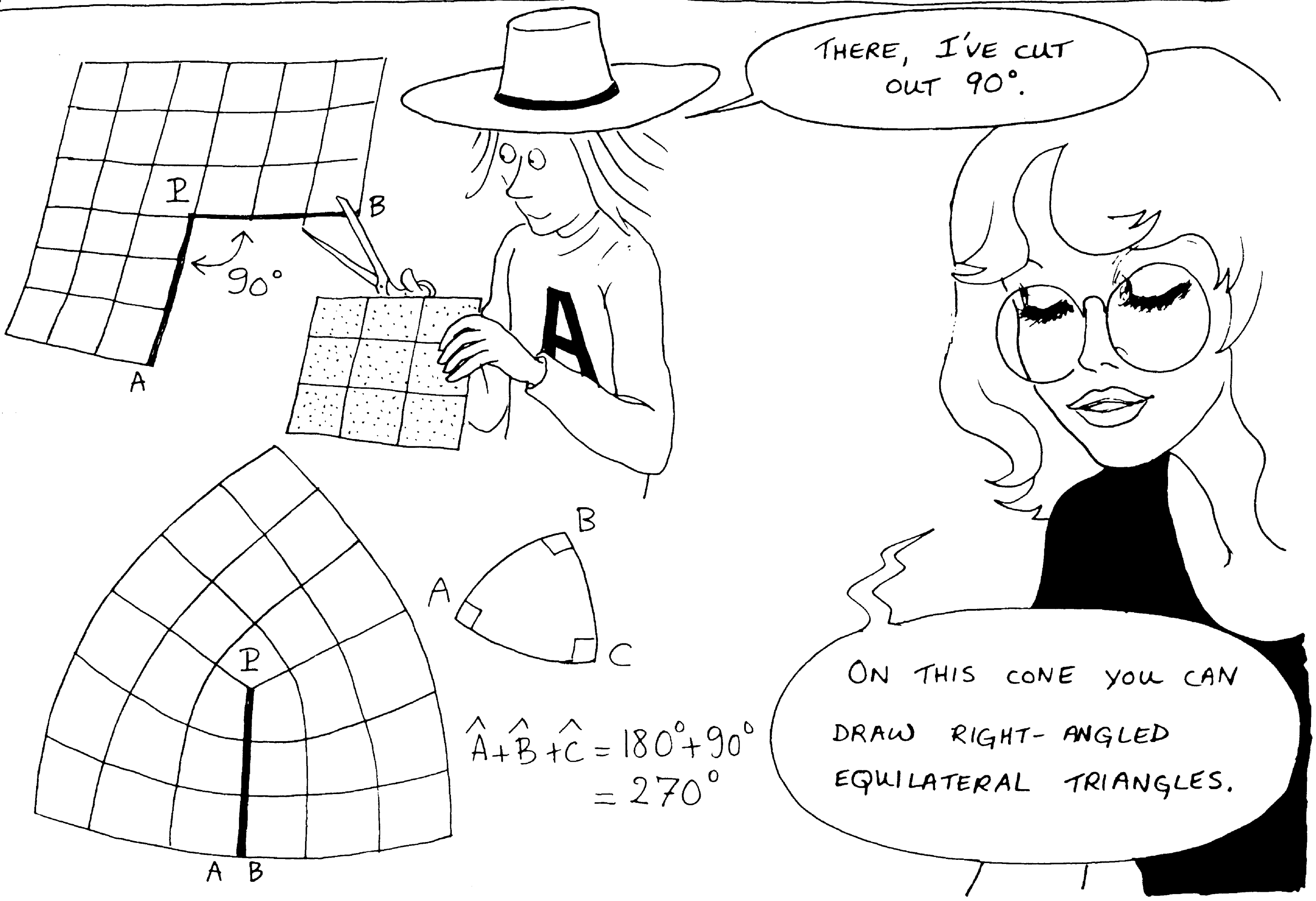
(*) YOU CAN'T DRAW A PARALLEL ON A SPHERE WITH STICKY TAPE, EXCEPT AT THE EQUATOR. TRY IT ON A BASKETBALL.

HERE'S WHY THE ANGLE-SUM OF A TRIANGLE, ON A POSICONE, IS INCREASED BY THE ANGLE θ OF THE CUT.

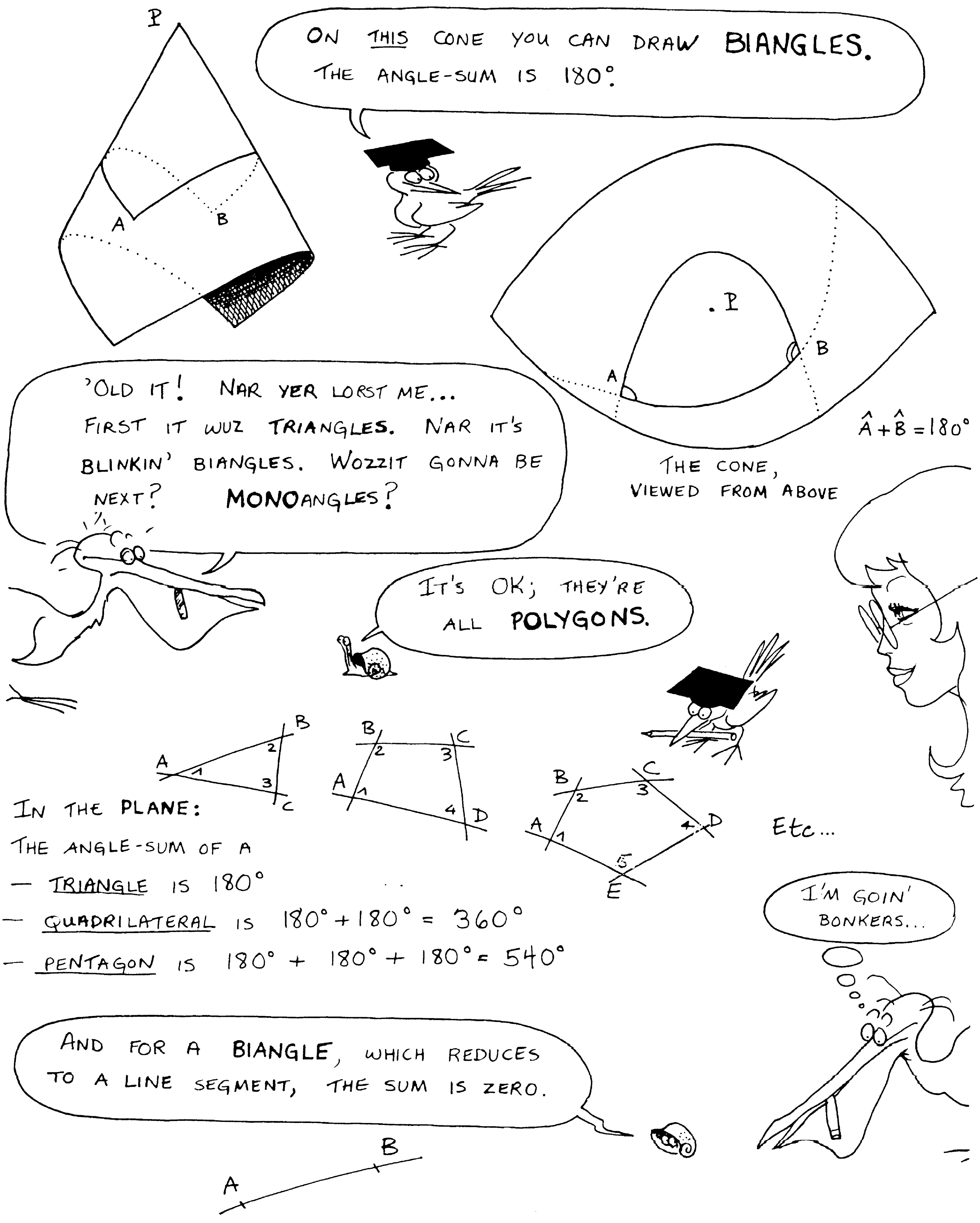


ARCHIBALD HIGGINS WILL NOW CONSTRUCT SPECIAL CONES, WHICH KEEP THE TILING REGULAR.

The Boss

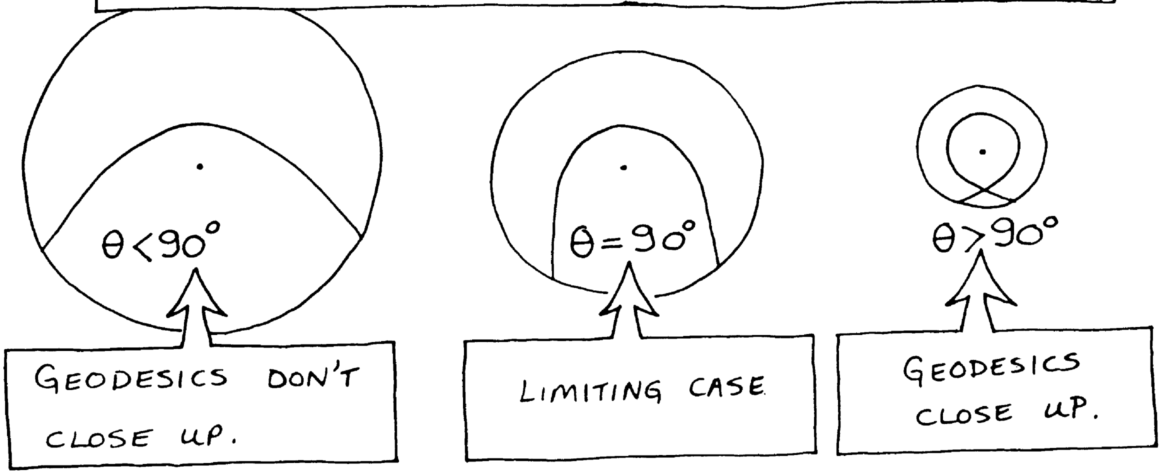


B
P
180°
A
NOW I EXCISE A SECTOR OF 180°.
P
A
B
ON THIS CONE, YER GITS A H'ANGLE-SUM OF 360°.
WHICH IMPLIES THAT YOU CAN DRAW ON IT, USING GEODESICS, A TRIANGLE HAVING THREE ANGLES OF 120°— THAT IS, OBTUSE.
120°
AND IT STILL CLOSES UP? THAT'S WEIRD.
HUM...
SEEMS TER ME, TIRESIAS, THAT YOU'RE THE ONE WOT'S H'OBTUSE!
ME?

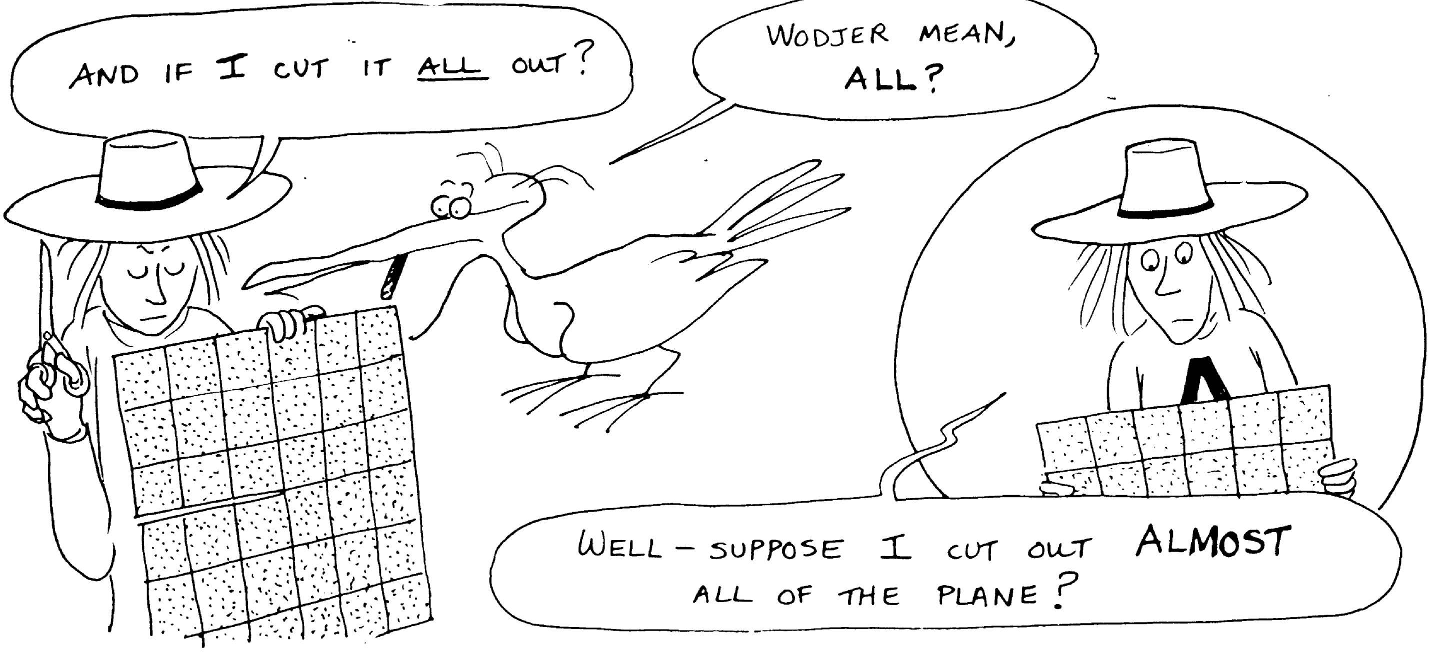

P
ON THIS CONE YOU CAN DRAW BIANGLES. THE ANGLE-SUM IS 180°
A
B
. P
A
B
$\hat{A} + \hat{B} = 180°$
THE CONE, VIEWED FROM ABOVE
'OLD IT! NAR YER LORST ME... FIRST IT WUZ TRIANGLES. N'AR IT'S BLINKIN' BIANGLES. WOZZIT GONNA BE NEXT? MONOANGLES?
IT'S OK; THEY'RE ALL POLYGONS.
A B C 1 2 3
A B C D 1 2 3 4
A B C D E 1 2 3 4 5
Etc...
IN THE PLANE:
THE ANGLE-SUM OF A
— TRIANGLE IS 180°
— QUADRILATERAL IS 180° + 180° = 360°
— PENTAGON IS 180° + 180° + 180° = 540°
I'M GOIN' BONKERS...
AND FOR A BIANGLE, WHICH REDUCES TO A LINE SEGMENT, THE SUM IS ZERO.
A
B

WHY THE H'EXTRA 180° EVERY TIME YER ADDS A CORNER?
2
180°
1
4
3
HA!
A SIMPLE KARATE CHOP WILL MAKE IT CLEAR...
ALL RIGHT, YOU TWO, LET'S GET ON WITH IT.
NOW I CUT OUT THREE QUARTERS OF THE PLANE.
B
P
A
P
B A
YOU MIGHT CALL THAT A NAPKONE.
AND WHEN I LOOK AT THE END...
B
P
A
ARCHIE SEES THIS

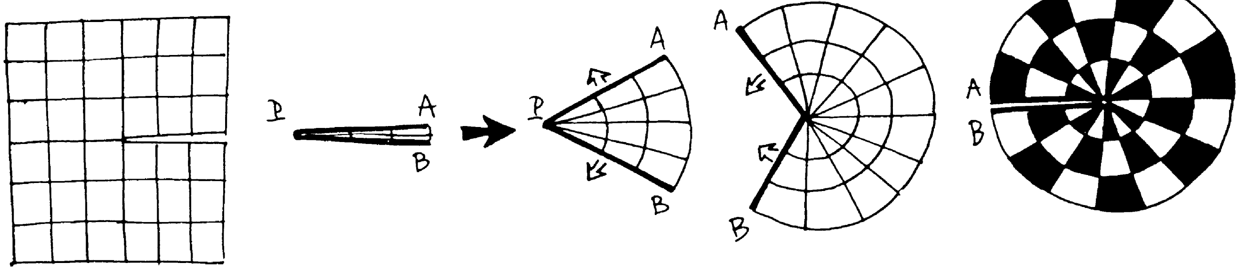
• IT ALL DEPENDS ON THE ANGLE θ OF THE CONE. •

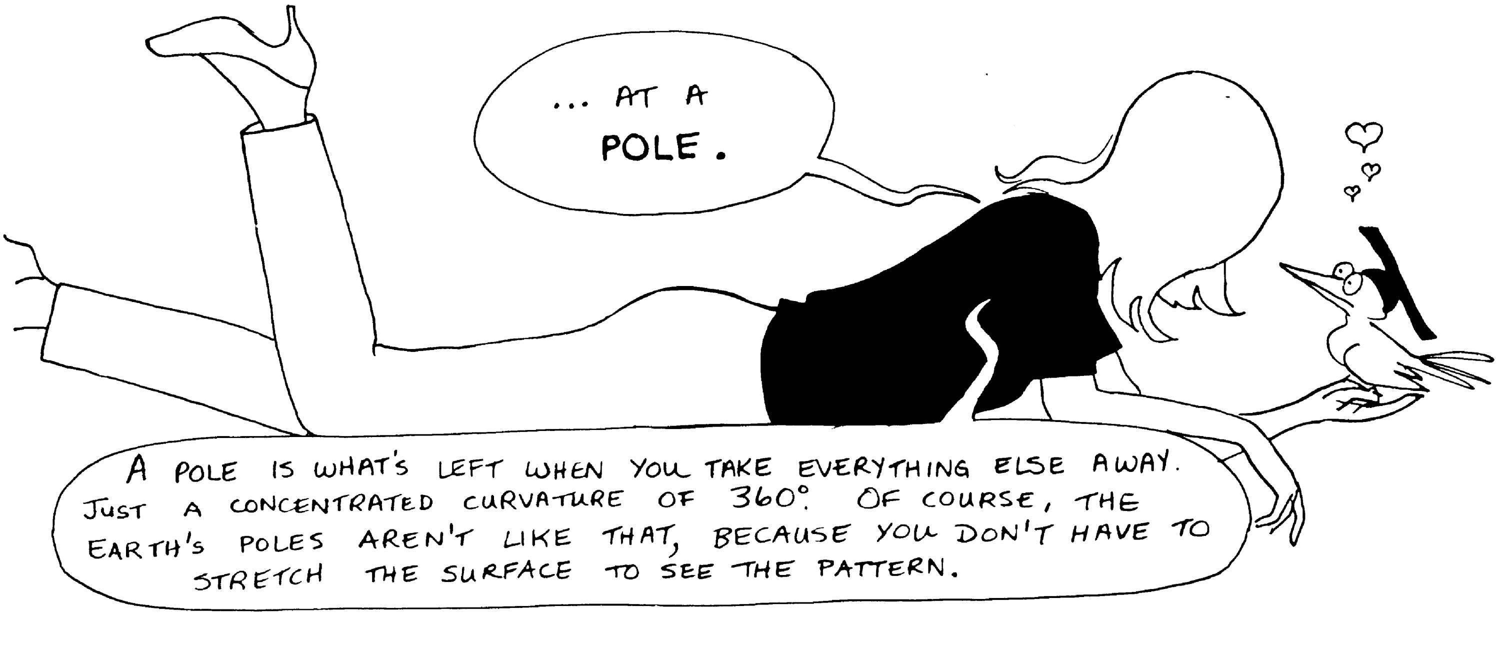


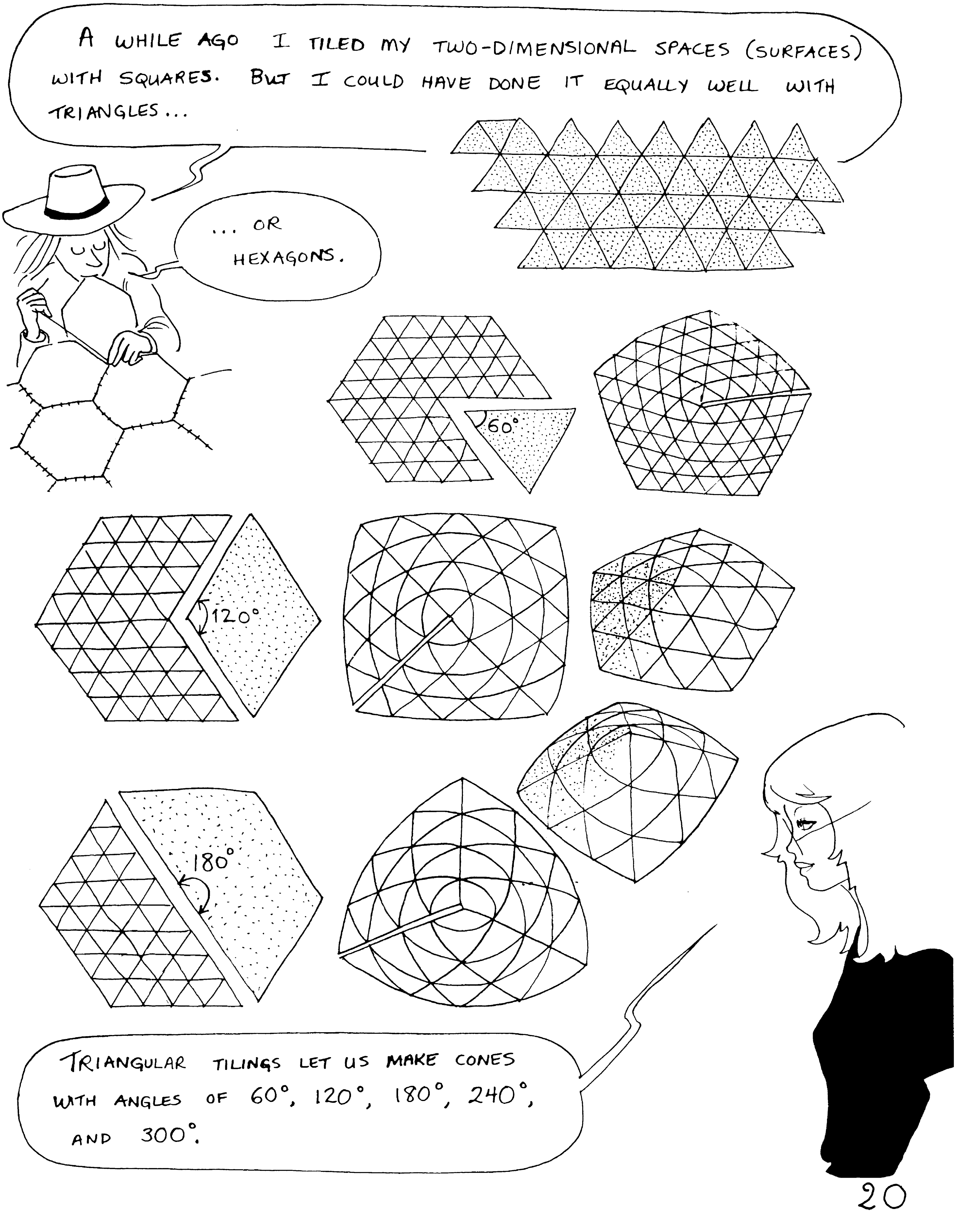
POLES

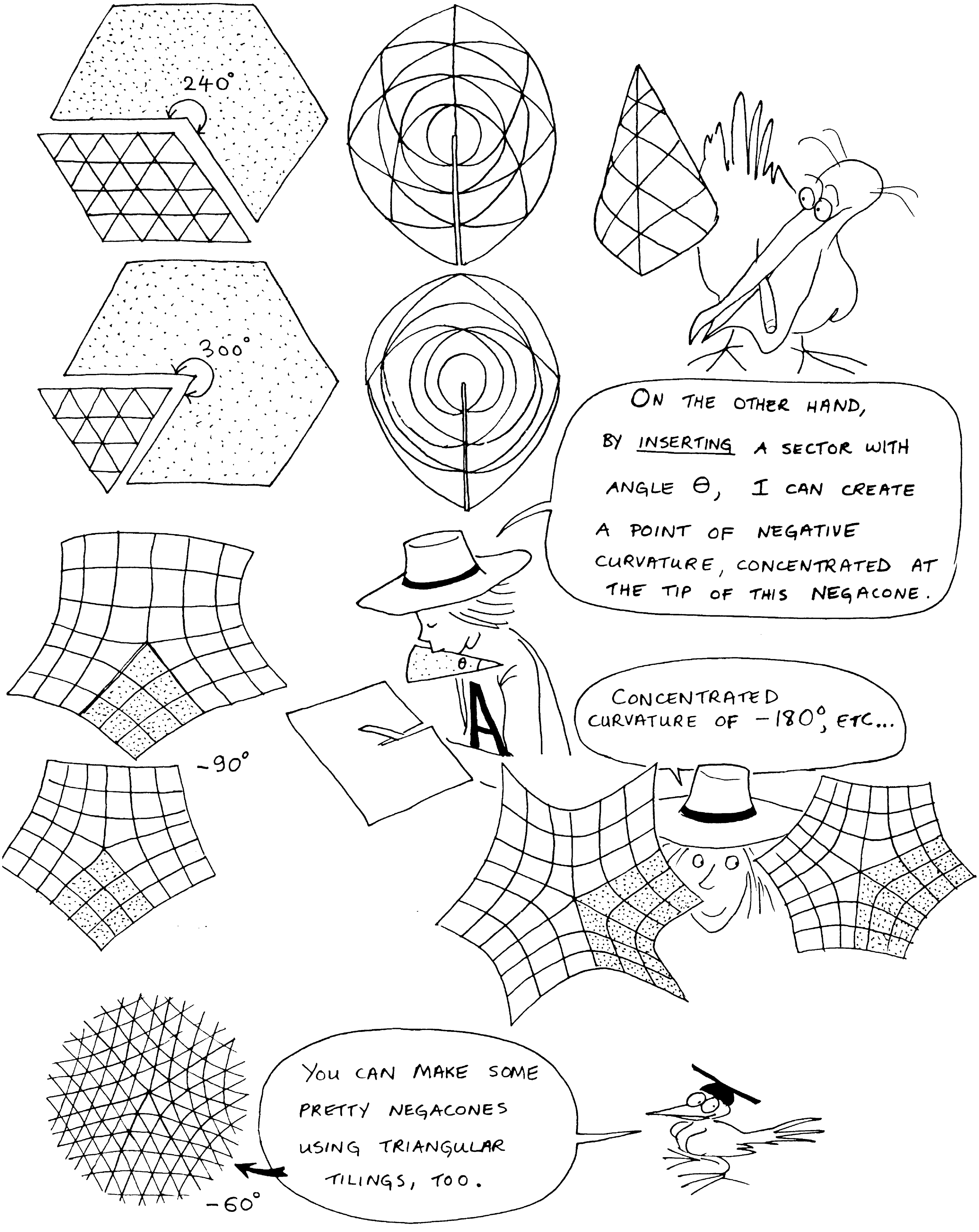


REMOVING ALMOST ALL OF THE PLANE AND APPLYING THIS PROCEDURE IN REVERSE, YOU GET THIS: A PATTERN LIKE MERIDIANS AND PARALLELS...

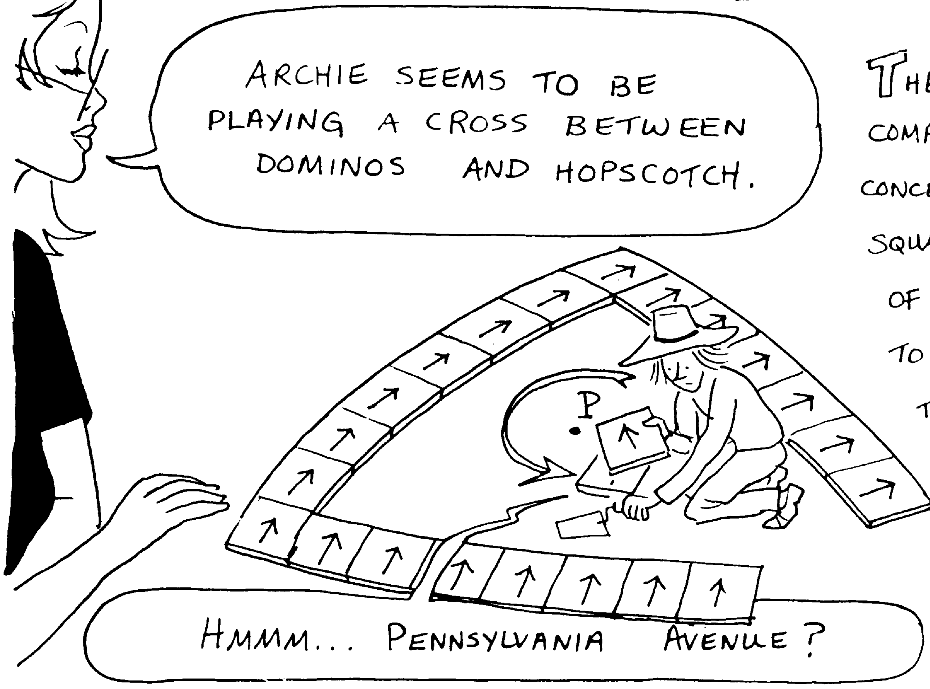





A WHILE AGO I TILED MY TWO-DIMENSIONAL SPACES (SURFACES) WITH SQUARES. BUT I COULD HAVE DONE IT EQUALLY WELL WITH TRIANGLES...
... OR HEXAGONS.
60°
120°
180°
TRIANGULAR TILINGS LET US MAKE CONES WITH ANGLES OF 60°, 120°, 180°, 240°, AND 300°.


240°
300°
ON THE OTHER HAND, BY INSERTING A SECTOR WITH ANGLE θ, I CAN CREATE A POINT OF NEGATIVE CURVATURE, CONCENTRATED AT THE TIP OF THIS NEGACONE.
θ
A
CONCENTRATED CURVATURE OF −180°, ETC...
−90°
YOU CAN MAKE SOME PRETTY NEGACONES USING TRIANGULAR TILINGS, TOO.
−60°

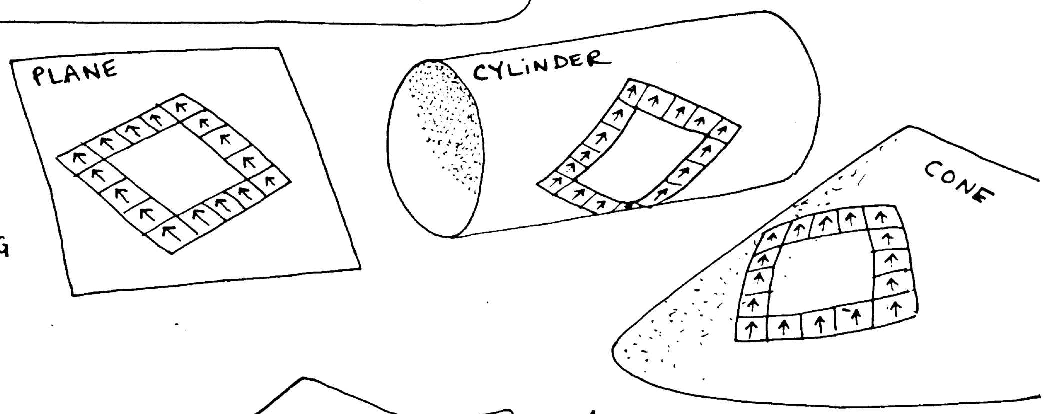
MEASURING CURVATURE

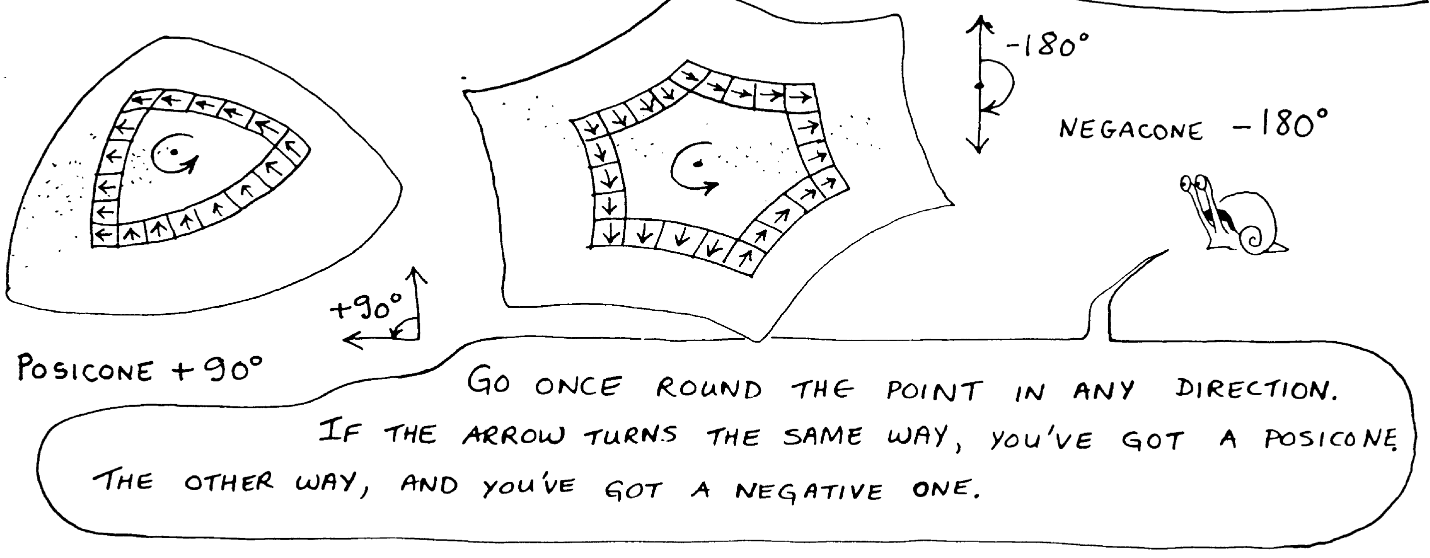


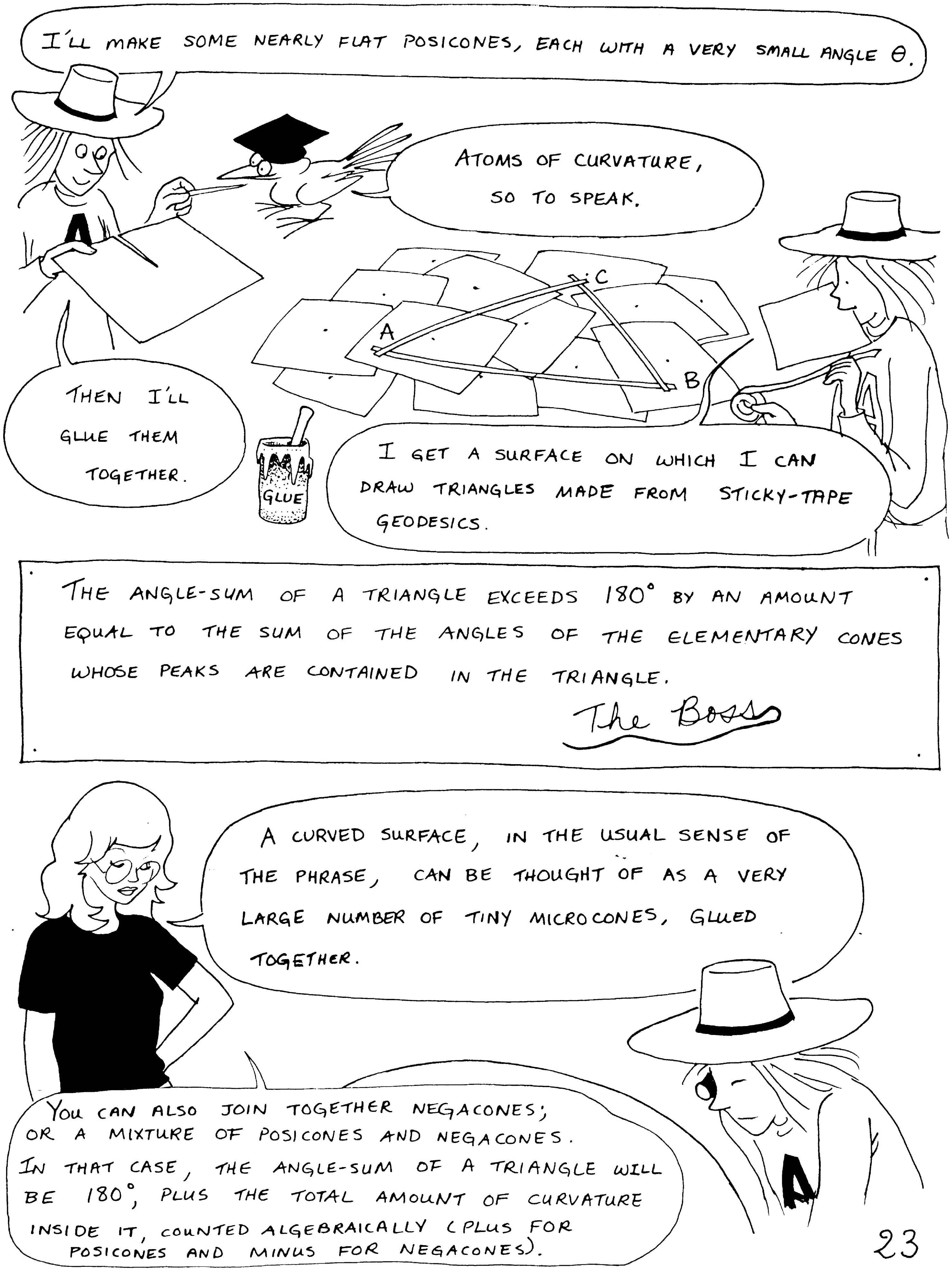
THE OBJECT OF THE GAME IS TO COMPLETELY SURROUND A POINT OF CONCENTRATED CURVATURE WITH SQUARES, KEEPING THE DIRECTION OF THE ARROW THE SAME FROM ONE TO THE NEXT. WHEN YOU GO ALL THE WAY ROUND P, THE ANGLE THROUGH WHICH THE ARROW HAS TURNED GIVES A DIRECT MEASURE OF THE CURVATURE θ.

SOME EXAMPLES:

PLANE, CYLINDER, CONE (NOT SURROUNDING THE TIP) – CURVATURE ZERO.

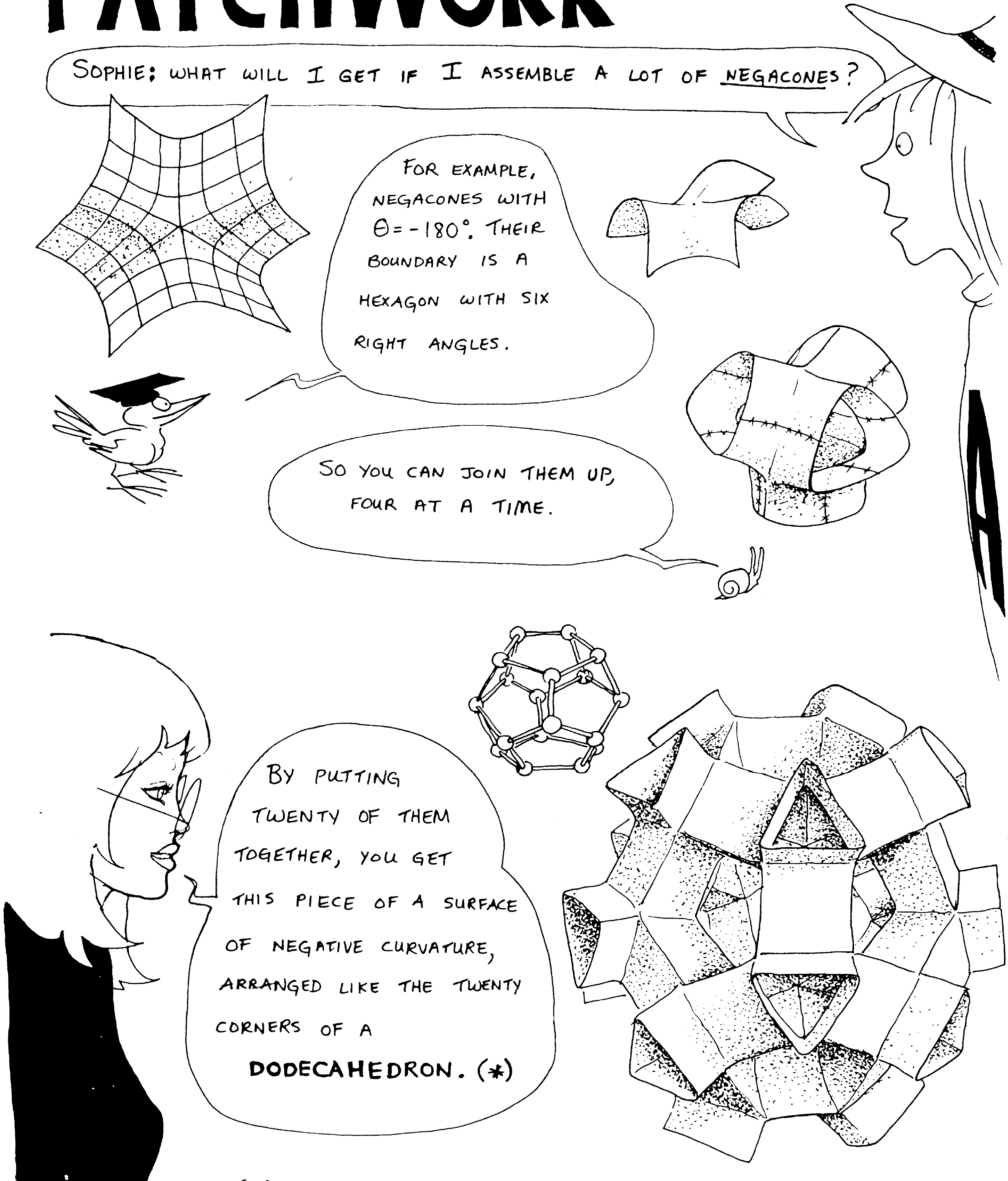




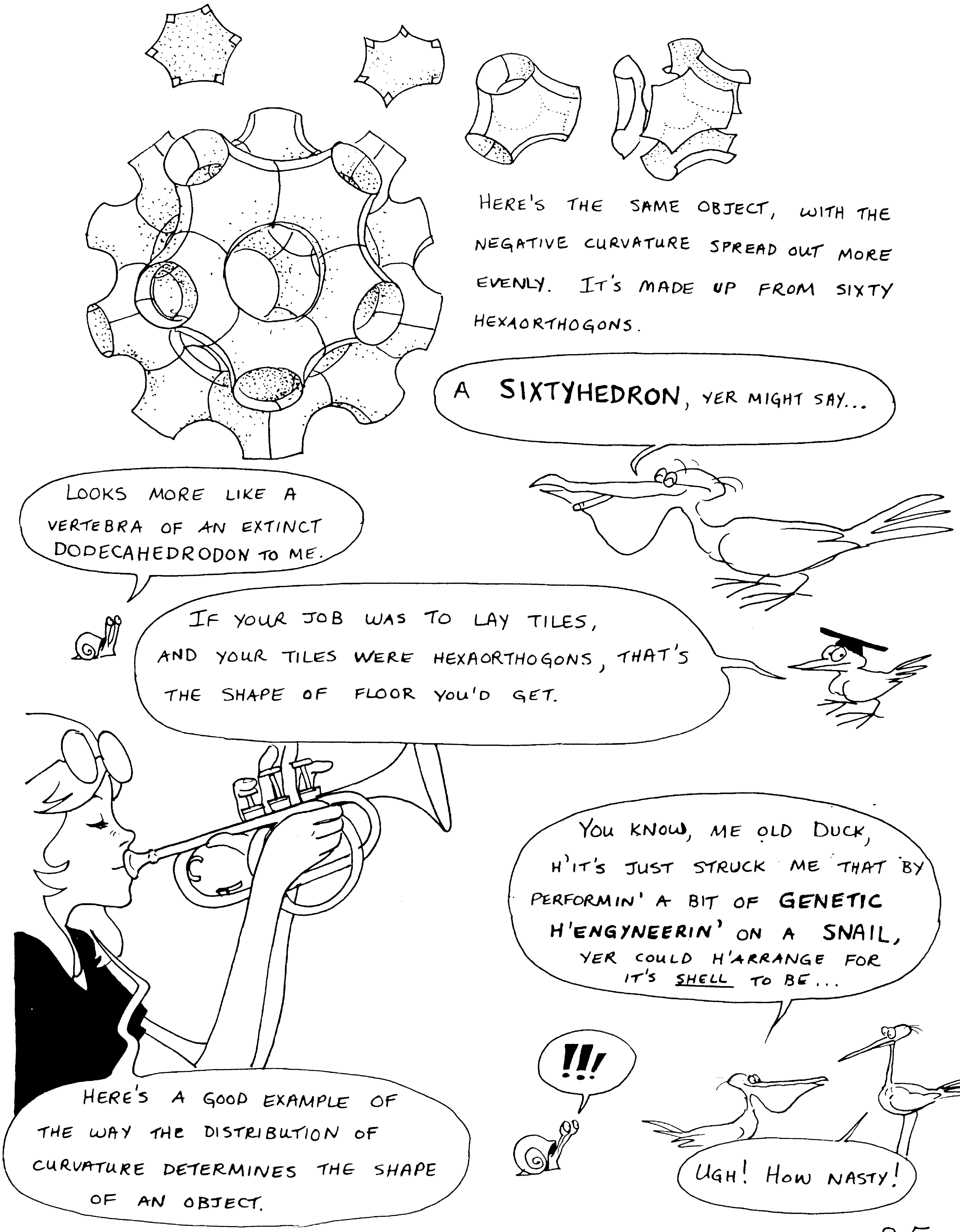


I'LL MAKE SOME NEARLY FLAT POSICONES, EACH WITH A VERY SMALL ANGLE θ.
ATOMS OF CURVATURE, SO TO SPEAK.
A
C
B
THEN I'LL GLUE THEM TOGETHER.
GLUE
I GET A SURFACE ON WHICH I CAN DRAW TRIANGLES MADE FROM STICKY-TAPE GEODESICS.
THE ANGLE-SUM OF A TRIANGLE EXCEEDS 180° BY AN AMOUNT EQUAL TO THE SUM OF THE ANGLES OF THE ELEMENTARY CONES WHOSE PEAKS ARE CONTAINED IN THE TRIANGLE.
The Boss
A CURVED SURFACE, IN THE USUAL SENSE OF THE PHRASE, CAN BE THOUGHT OF AS A VERY LARGE NUMBER OF TINY MICROCONES, GLUED TOGETHER.
YOU CAN ALSO JOIN TOGETHER NEGACONES; OR A MIXTURE OF POSICONES AND NEGACONES. IN THAT CASE, THE ANGLE-SUM OF A TRIANGLE WILL BE 180°, PLUS THE TOTAL AMOUNT OF CURVATURE INSIDE IT, COUNTED ALGEBRAICALLY (PLUS FOR POSICONES AND MINUS FOR NEGACONES).

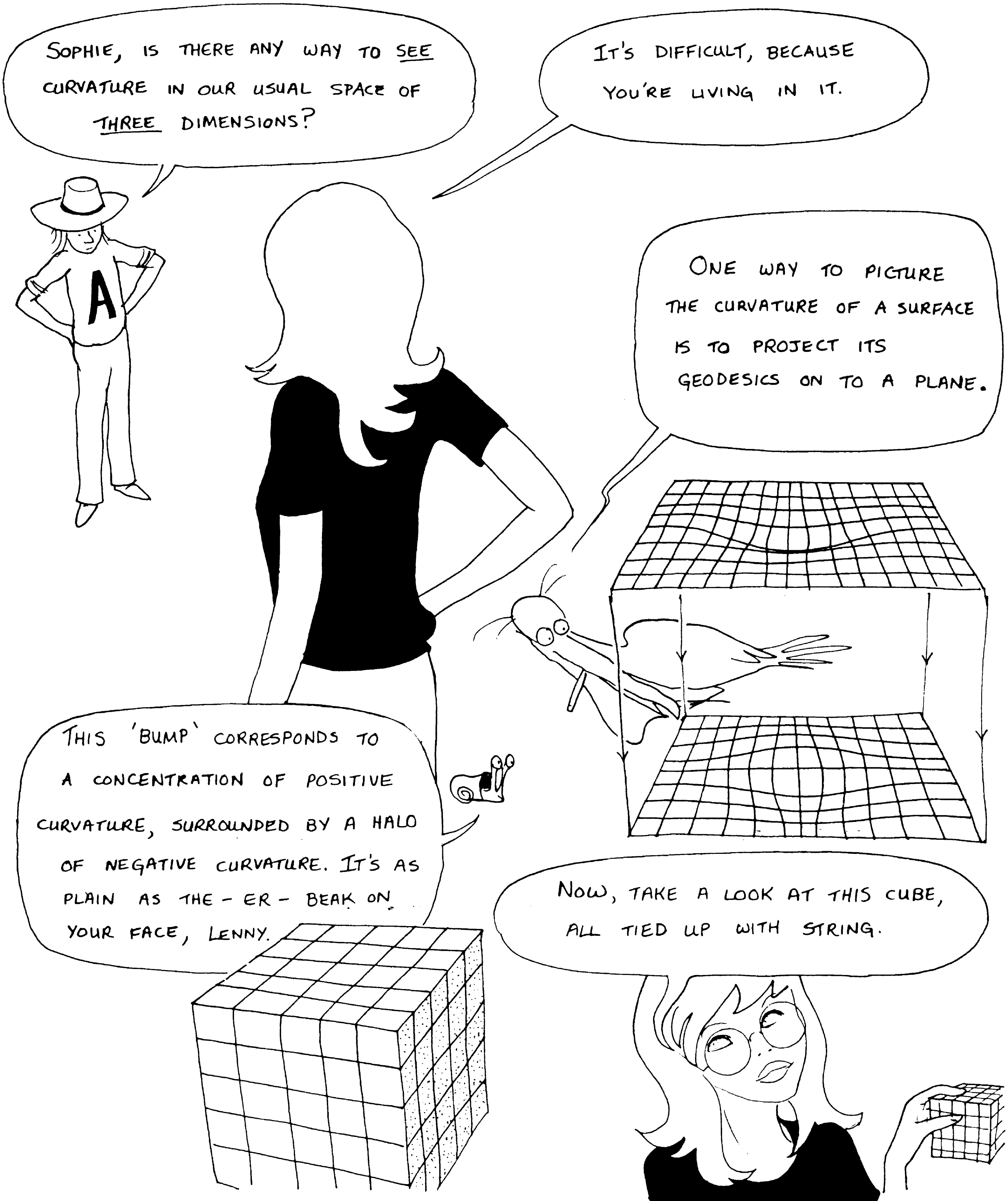
PATCHWORK

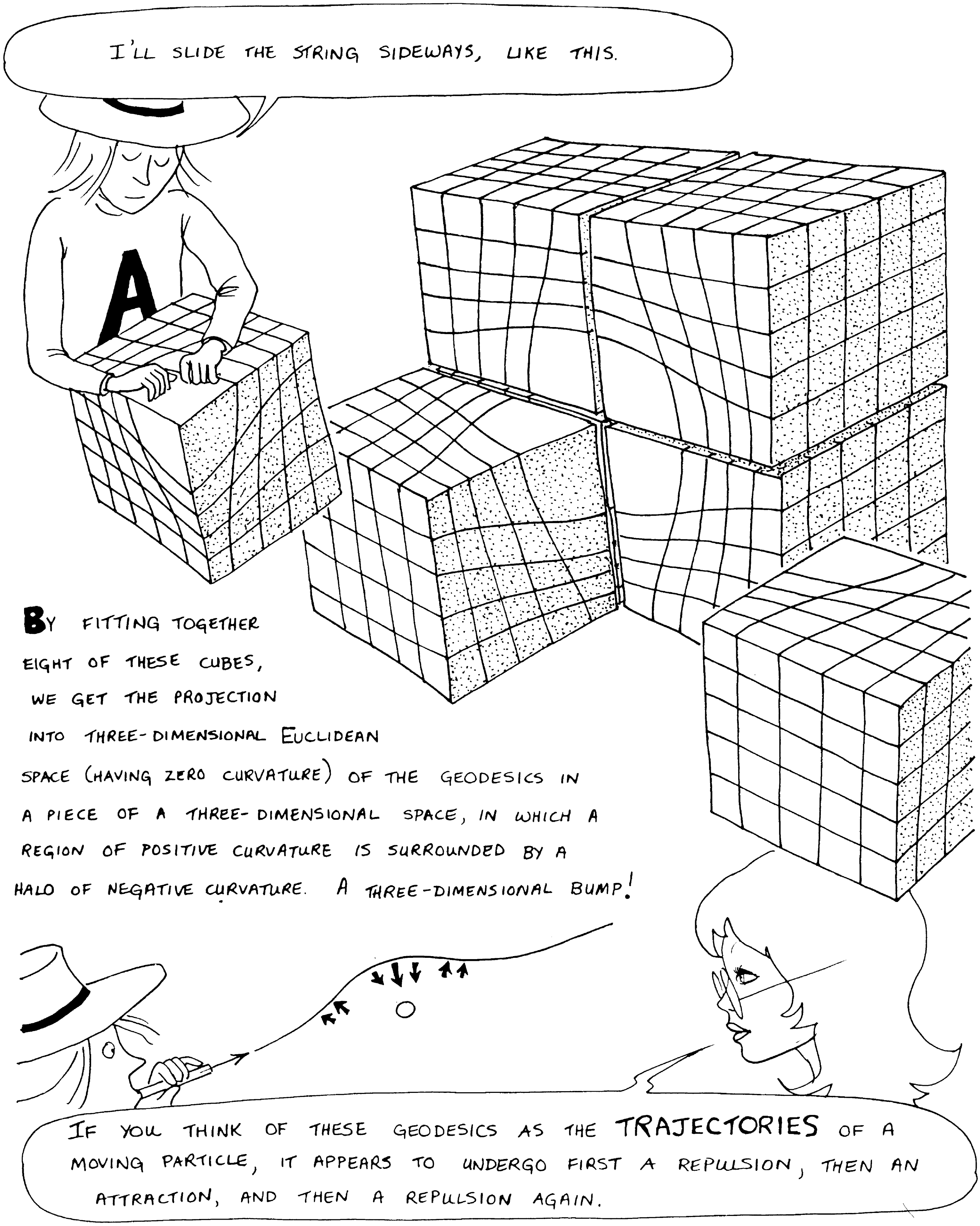


(*) FROM THE GREEK: DODEKA = TWELVE 'EDRON = SIDE

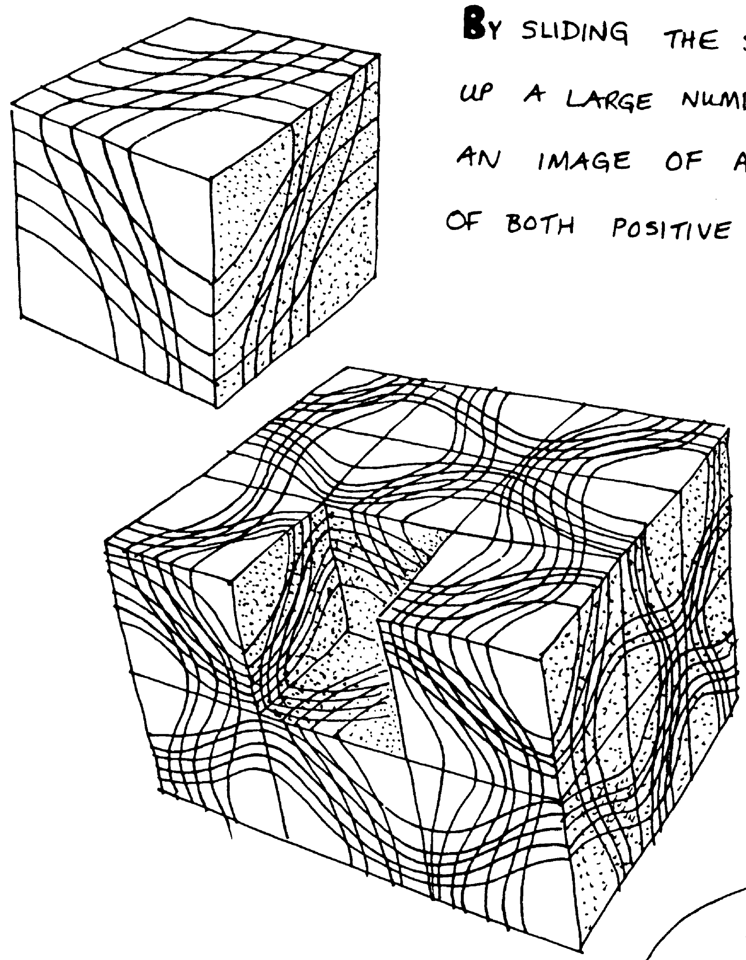

HERE'S THE SAME OBJECT, WITH THE NEGATIVE CURVATURE SPREAD OUT MORE EVENLY. IT'S MADE UP FROM SIXTY HEXAORTHOGONS.
A **SIXTYHEDRON**, YER MIGHT SAY...
LOOKS MORE LIKE A VERTEBRA OF AN EXTINCT DODECAHEDRODON TO ME.
IF YOUR JOB WAS TO LAY TILES, AND YOUR TILES WERE HEXAORTHOGONS, THAT'S THE SHAPE OF FLOOR YOU'D GET.
YOU KNOW, ME OLD DUCK, H'IT'S JUST STRUCK ME THAT BY PERFORMIN' A BIT OF **GENETIC H'ENGYNEERIN'** ON A **SNAIL**, YER COULD H'ARRANGE FOR IT'S SHELL TO BE...
!!!
UGH! HOW NASTY!
HERE'S A GOOD EXAMPLE OF THE WAY THE DISTRIBUTION OF CURVATURE DETERMINES THE SHAPE OF AN OBJECT.

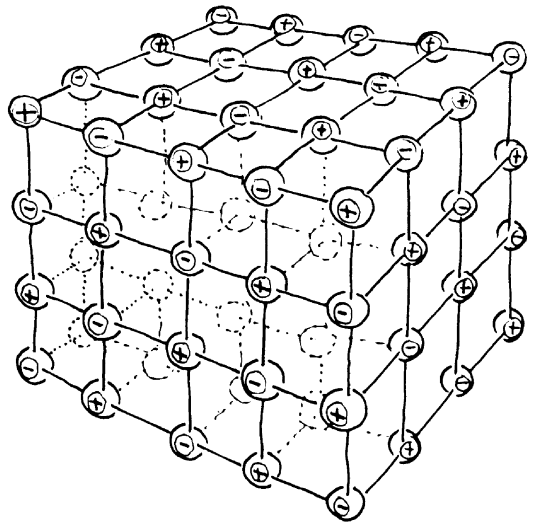
THREE DIMENSIONS

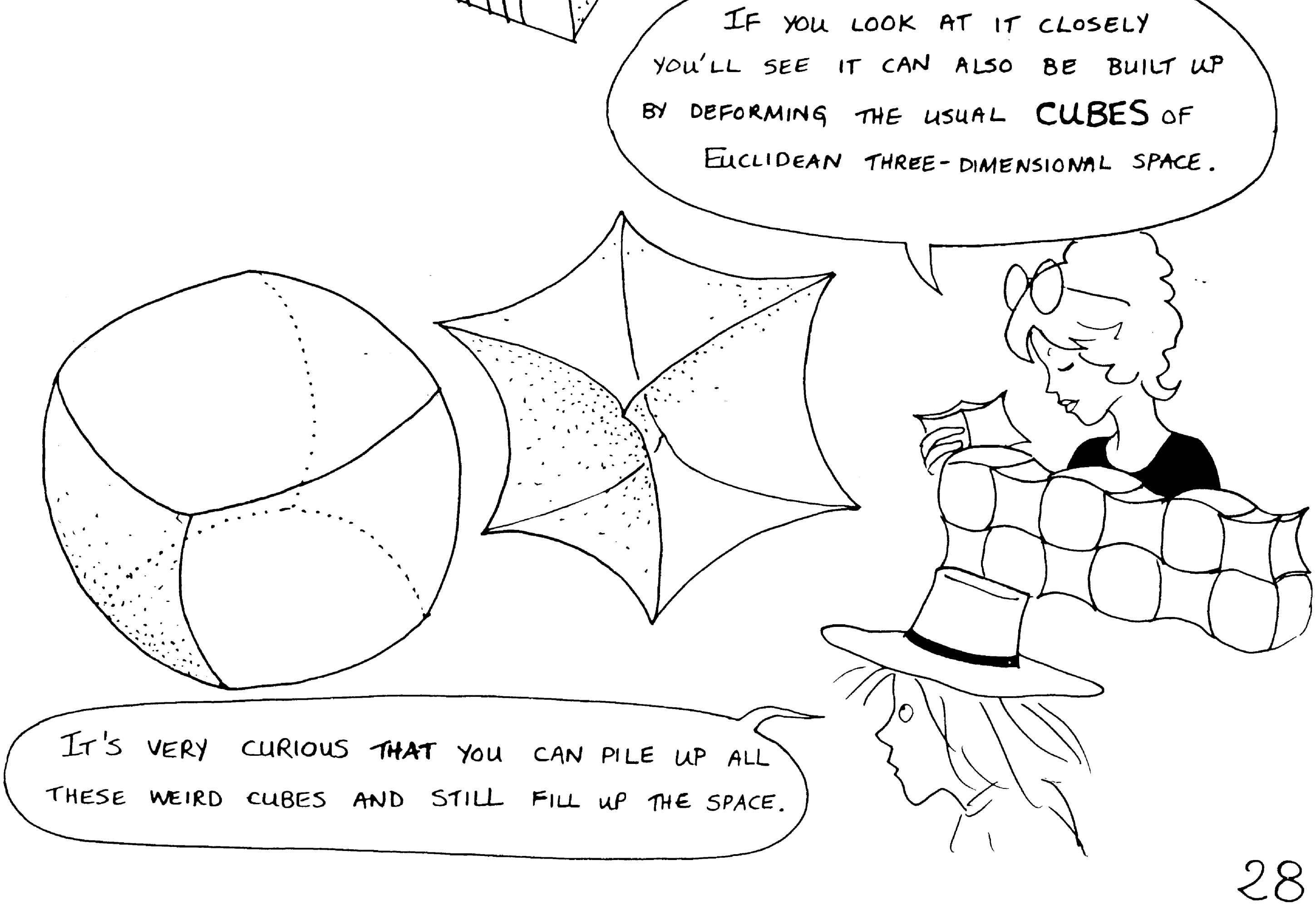



I'LL SLIDE THE STRING SIDEWAYS, LIKE THIS.
BY FITTING TOGETHER EIGHT OF THESE CUBES, WE GET THE PROJECTION INTO THREE-DIMENSIONAL EUCLIDEAN SPACE (HAVING ZERO CURVATURE) OF THE GEODESICS IN A PIECE OF A THREE-DIMENSIONAL SPACE, IN WHICH A REGION OF POSITIVE CURVATURE IS SURROUNDED BY A HALO OF NEGATIVE CURVATURE. A THREE-DIMENSIONAL BUMP!
IF YOU THINK OF THESE GEODESICS AS THE TRAJECTORIES OF A MOVING PARTICLE, IT APPEARS TO UNDERGO FIRST A REPULSION, THEN AN ATTRACTION, AND THEN A REPULSION AGAIN.

By sliding the strings like this, and joining up a large number of cubes, you can produce an image of a world populated by regions of both positive and negative curvature:



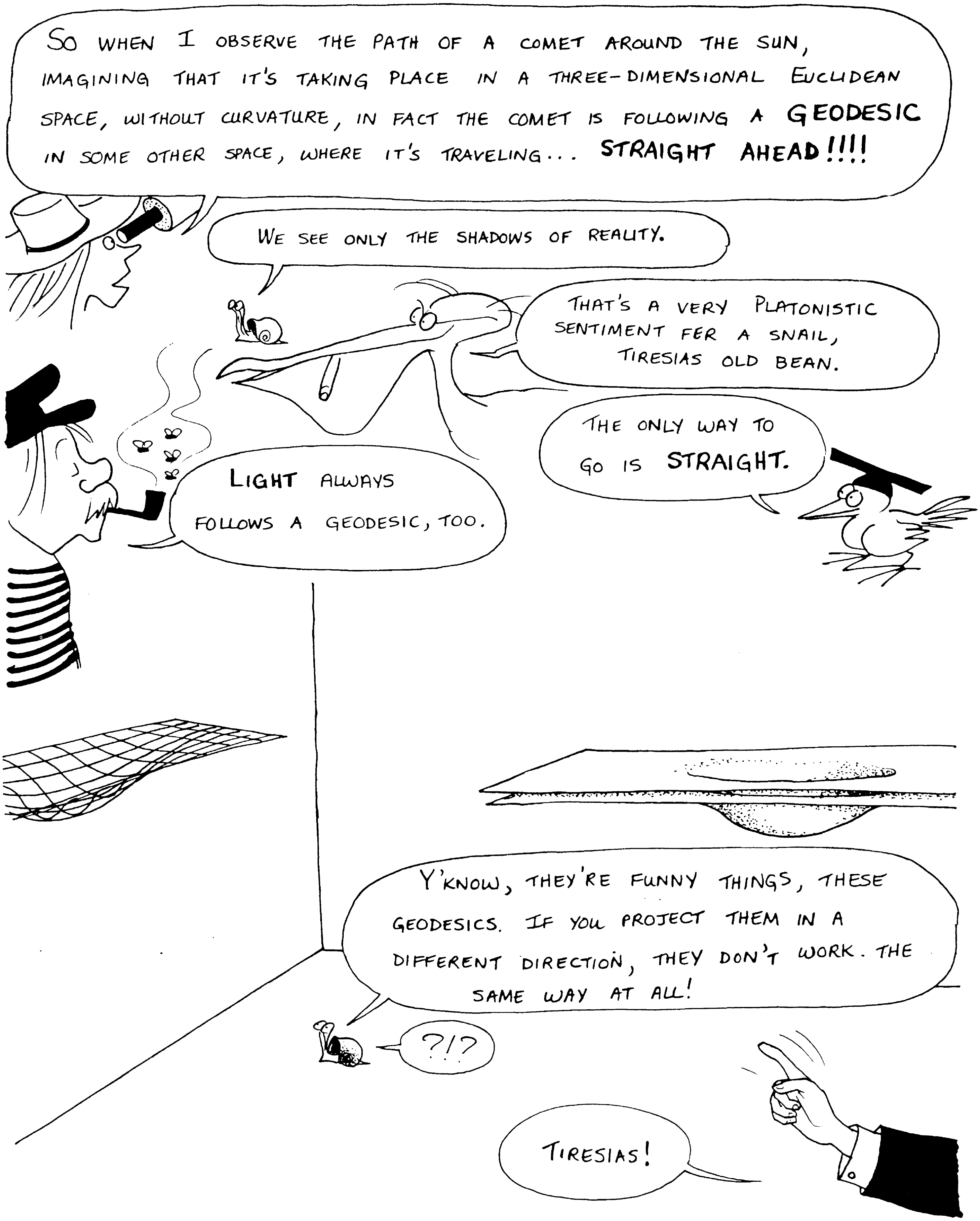




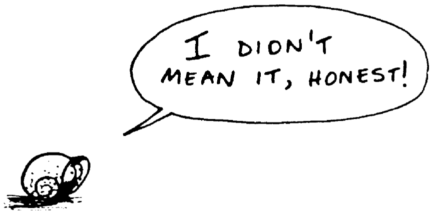
PROJECTiONS


LET ME CHECK I'VE GOT ALL THIS STRAIGHT, MR. ALBERT. YOU'RE SAYING THAT BENDS IN TRAJECTORIES, CAUSED BY FORCES, ARE REALLY JUST AN EFFECT OF THE PROJECTION, INTO OUR USUAL WORLD, OF A GEODESIC TRAJECTORY ON SOME OTHER SURFACE.
MORE RUDDY METAFIZZICKS!
NO, JUST GEOMETRY.
I GIF' YOU AN EXAMPLE. IMACHIN' YOURSELF TO BE IN A SPACE CAPSULE, IN ORBIT AROUND DER EARTH.
CRIKEY! WE'VE GONE WEIGHTLESS!
OH 'ECK!
¡IW
NOW WE CAN PLAY A RATHER UNUSUAL KIND OF BILLIARDS.

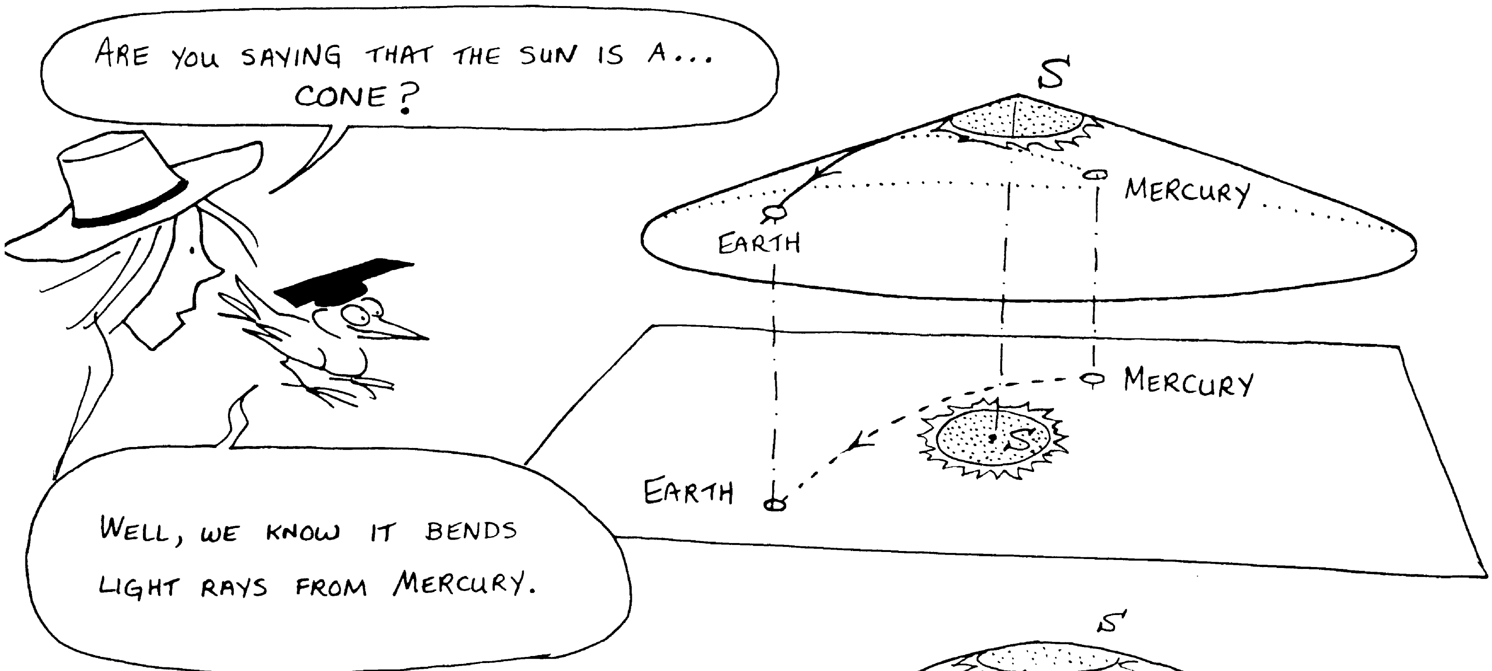

AS FAR AS I CAN TELL, THIS THING SEEMS TO BE BUILT FROM TWO TRANSPARENT SURFACES, WITH LOTS OF FOLDS AND DENTS, BOTH EXACTLY THE SAME AND LYING PARALLEL TO EACH OTHER.
DAT PERMITS ME TO SHOOT DER TINY MARPLES BETWEEN DEM AND OBSERVE DERE TRAJECTORIES.
V
THE TRAJECTORIES DO NOT DEPEND ON THE SPEED V BECAUSE THIS IS DEEMED TO BE CONSTANT THROUGHOUT THE MOTION.
The Boss
IN YUST DIS CASE, IT FOLLOWS DAT ALL POSSIBLE TRAJECTORIES ARE GEODESICS. (IF WE WEREN'T WEIGHTLESS, DIS WOULDN'T BE DER CASE.)
OH, LOOK: THE LAMP IS PROJECTING THE TRAJECTORIES ON TO THE FLOOR OF THE CAPSULE!
ANYONE WHO COULD ONLY SEE DER SHADOWS WOULD THINK DAT DER OBJECTS MOOFING IN DER PLANE WERE AFFECTED BY A FIELD OF FORCES. BUT REALLY IT'S ALL DUE TO DER CURFATURE OF DER SURFACE.

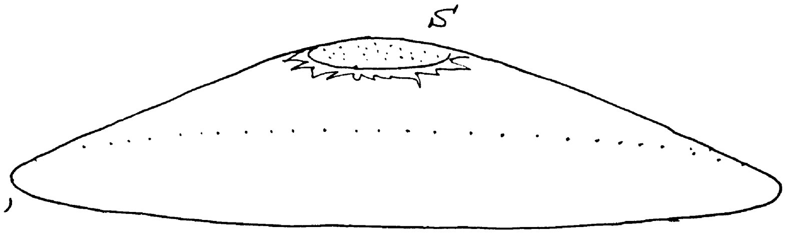


SO WHEN I OBSERVE THE PATH OF A COMET AROUND THE SUN, IMAGINING THAT IT'S TAKING PLACE IN A THREE-DIMENSIONAL EUCLIDEAN SPACE, WITHOUT CURVATURE, IN FACT THE COMET IS FOLLOWING A GEODESIC IN SOME OTHER SPACE, WHERE IT'S TRAVELING... STRAIGHT AHEAD!!!!
WE SEE ONLY THE SHADOWS OF REALITY.
THAT'S A VERY PLATONISTIC SENTIMENT FER A SNAIL, TIRESIAS OLD BEAN.
THE ONLY WAY TO GO IS STRAIGHT.
LIGHT ALWAYS FOLLOWS A GEODESIC, TOO.
Y'KNOW, THEY'RE FUNNY THINGS, THESE GEODESICS. IF YOU PROJECT THEM IN A DIFFERENT DIRECTION, THEY DON'T WORK. THE SAME WAY AT ALL!
?!?
TIRESIAS!

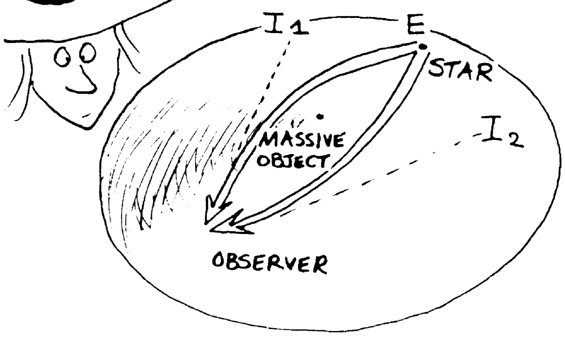


MASS AND MATTER



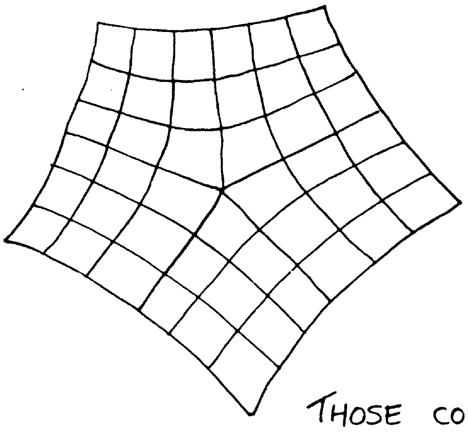


WE USUALLY THINK OF SPACE NEAR THE SUN AS BEING **FLAT**. BUT IN FACT, BECAUSE OF ITS LARGE MASS, THIS STAR REPRESENTS A CERTAIN AMOUNT OF CURVATURE. BUT BECAUSE THE SUN'S MASS ISN'T CONCENTRATED AT A POINT, WE'LL THINK OF THIS REGION OF SPACE AS A SMOOTHED-OUT CONE.

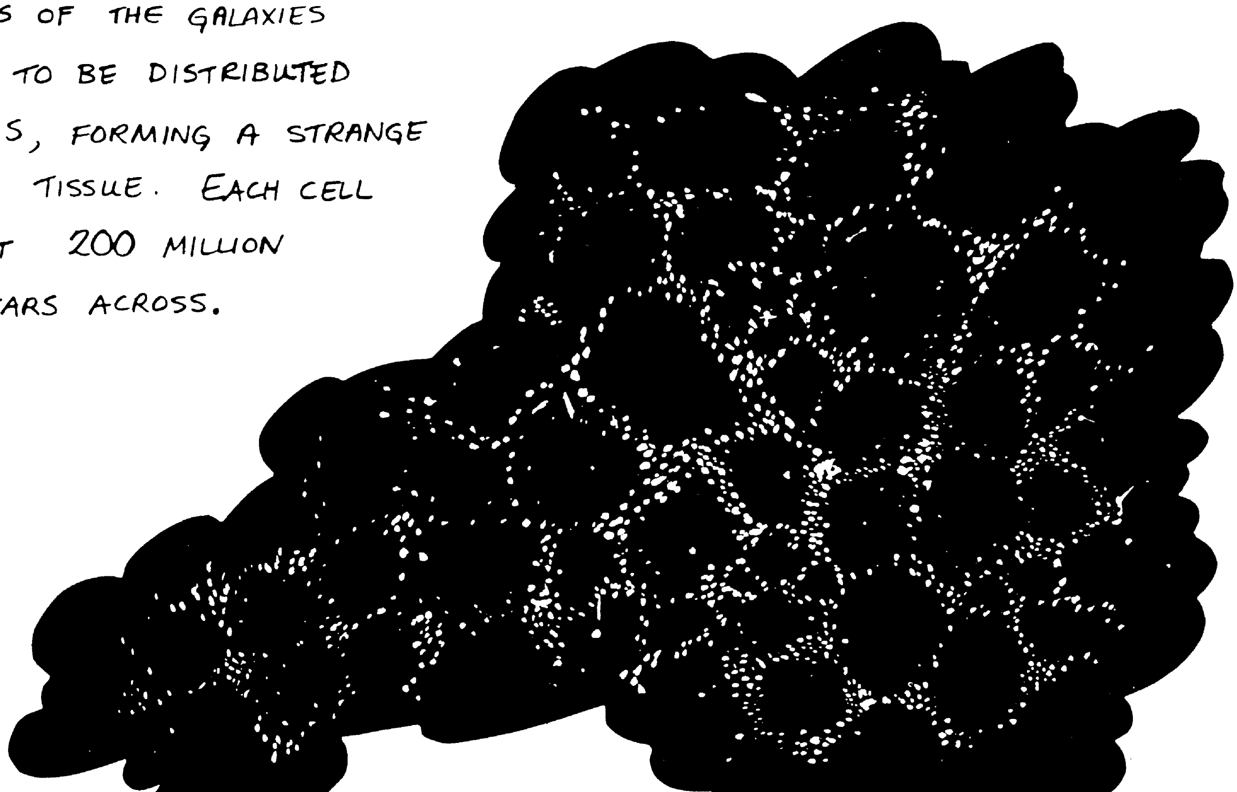


VERY MASSIVE OBJECTS CAN CURVE SPACE TO SUCH AN EXTENT THAT AN OBSERVER CAN SEE TWO IMAGES I_1 AND I_2 OF THE SAME STAR E. THIS EFFECT, KNOWN AS A GRAVITATIONAL LENS, HAS RECENTLY BEEN OBSERVED IN LIGHT FROM QUASARS.


THE MASSES OF ATOMS AND PARTICLES ALL CONTRIBUTE TO THE GENERAL CURVATURE OF THE UNIVERSE.
SO MASS HAS A GEOMETRIC SIGNIFICANCE.
'ANG ON, WOT ABAHT BETWEEN THE ATOMS? THERE'S NUFFIN' THERE!
I LORST THE THREAD AGAIN...
NOW MY DEAR FELLOW, HAVEN'T YOU HEARD THAT THE OLD OPPOSITION BETWEEN MATTER AND THE VOID IS TOTALLY OUTMODED? THE ONLY THING NOWADAYS IS GEOMETRY.
NUFFIN' BUT... GEOMETRY???

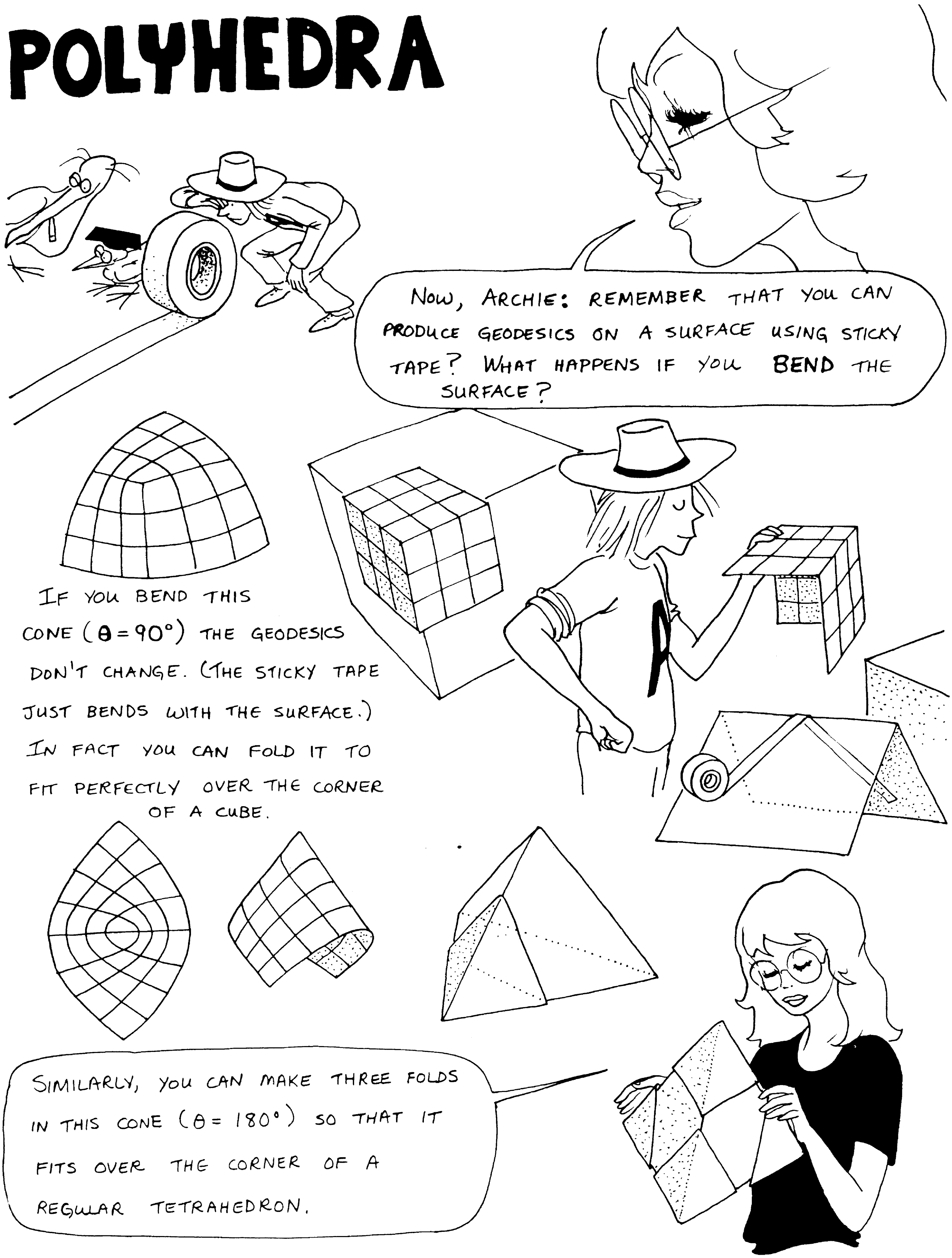


THOSE CONJURE UP THE IDEA OF "NEGATIVE MASS," PRODUCING A REPULSIVE FORCE. A UNIVERSE FULL OF NEGATIVE MASSES WOULD BE VERY PECULIAR. INSTEAD OF GALAXIES, THERE WOULD BE LOTS OF BUBBLES — ENORMOUS VOIDS. IN FACT, THE MASS OF THE GALAXIES SEEMS TO BE DISTRIBUTED LIKE THIS, FORMING A STRANGE CELLULAR TISSUE. EACH CELL IS ABOUT 200 MILLION LIGHT=YEARS ACROSS.

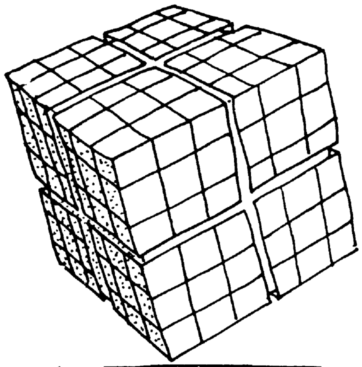
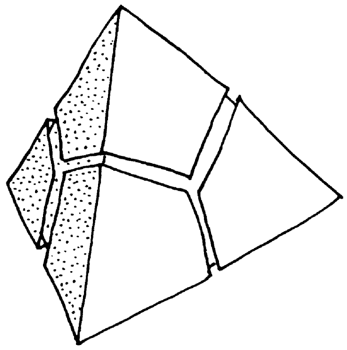
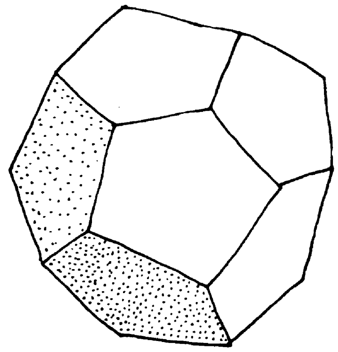


PERHAPS GRAVITATIONAL FORCES BECOME REPULSIVE AT A VERY LARGE DISTANCE.

POLYHEDRA


Now, Archie: remember that you can produce geodesics on a surface using sticky tape? What happens if you BEND the surface?
If you bend this cone ($\theta = 90°$) the geodesics don't change. (The sticky tape just bends with the surface.) In fact you can fold it to fit perfectly over the corner of a cube.
Similarly, you can make three folds in this cone ($\theta = 180°$) so that it fits over the corner of a regular tetrahedron.

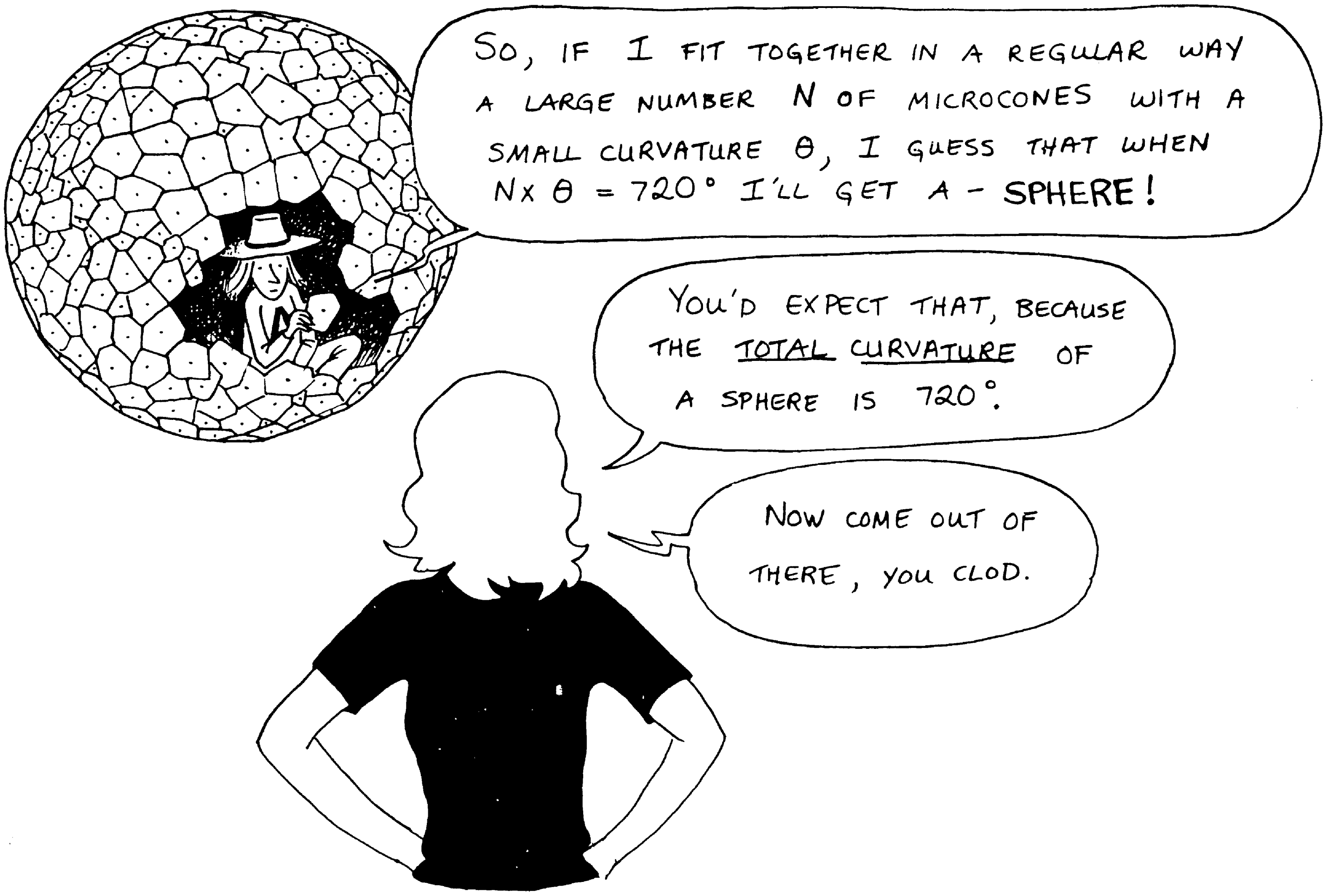
SPACE MUST BE OPEN OR CLOSED

EIGHT CONES ($\theta = 90°$) CAN BE USED TO MAKE A CUBE.
$90° \times 8 = 720°$

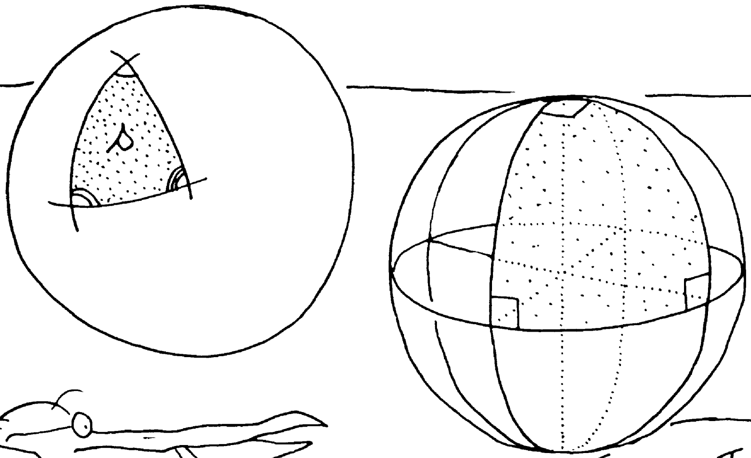
FOUR CONES ($\theta = 180°$) CAN BE USED TO MAKE A TETRAHEDRON.
$180° \times 4 = 720°$

TWENTY CONES ($\theta = 36°$) CAN BE USED TO MAKE A DODECAHEDRON.
$36° \times 20 = 720°$



On a sphere, the curvature is uniformly distributed. So the sum of the angles of a triangle drawn on a sphere is equal to $180° + 720° \times \frac{s}{S}$ where s is the area of the triangle and S the area of the sphere. The second term $720° \times \frac{s}{S}$ represents the **AMOUNT OF CURVATURE** contained in the triangle. (*)

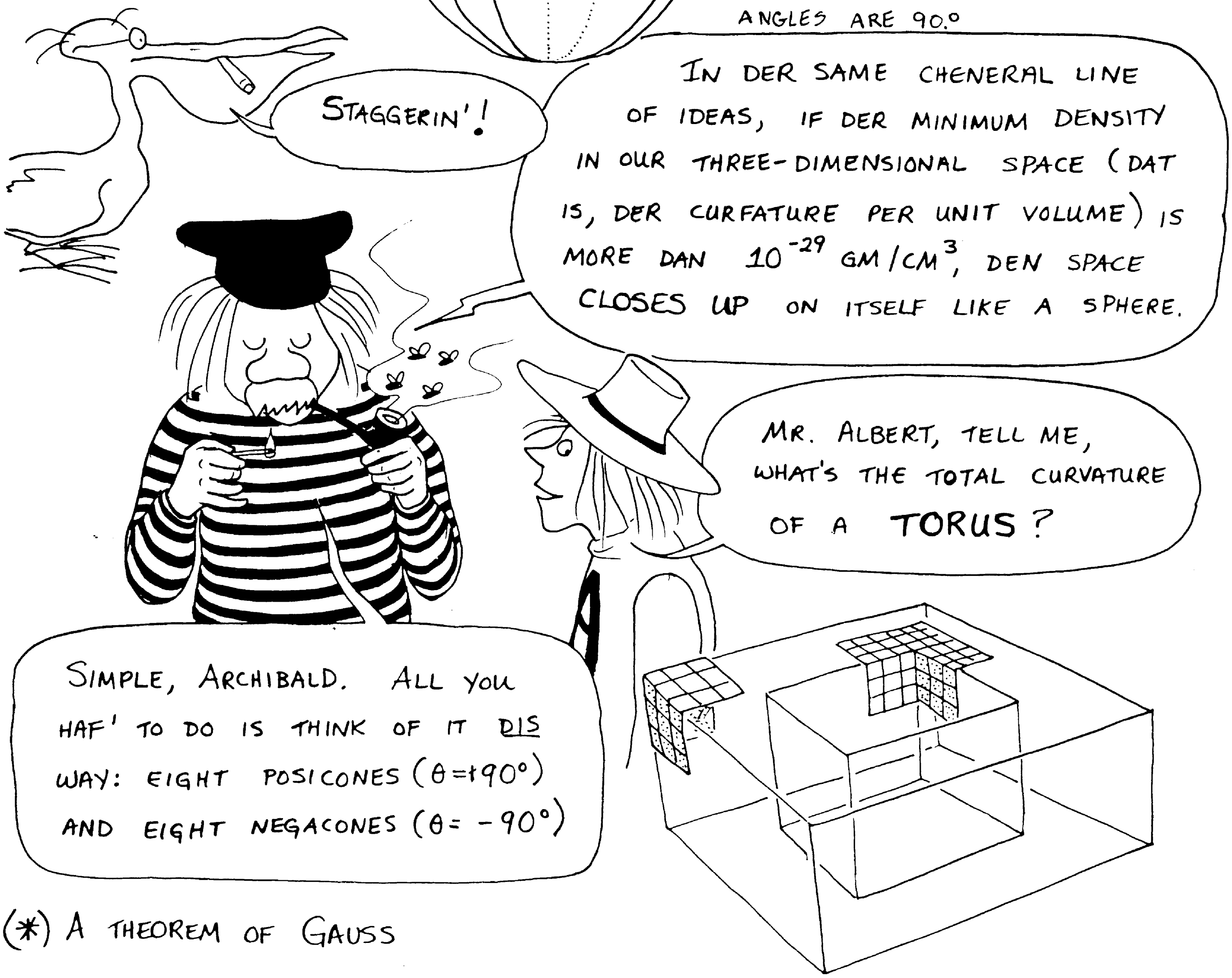
The Boss



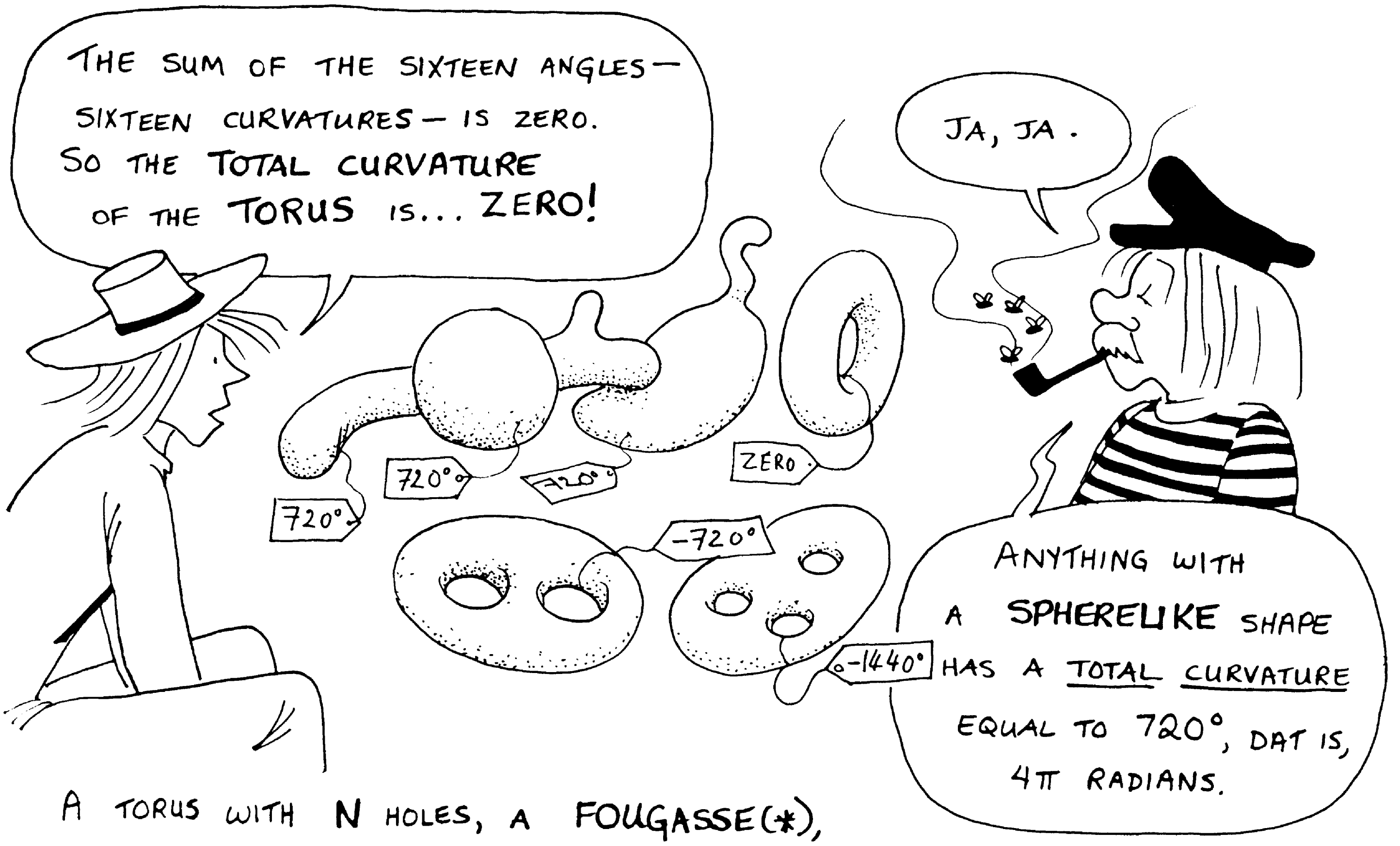
For example, this triangle takes up one eighth of the surface of a sphere, and:

$$\hat{A} + \hat{B} + \hat{C} = 180° + \frac{720°}{8} = 270°$$

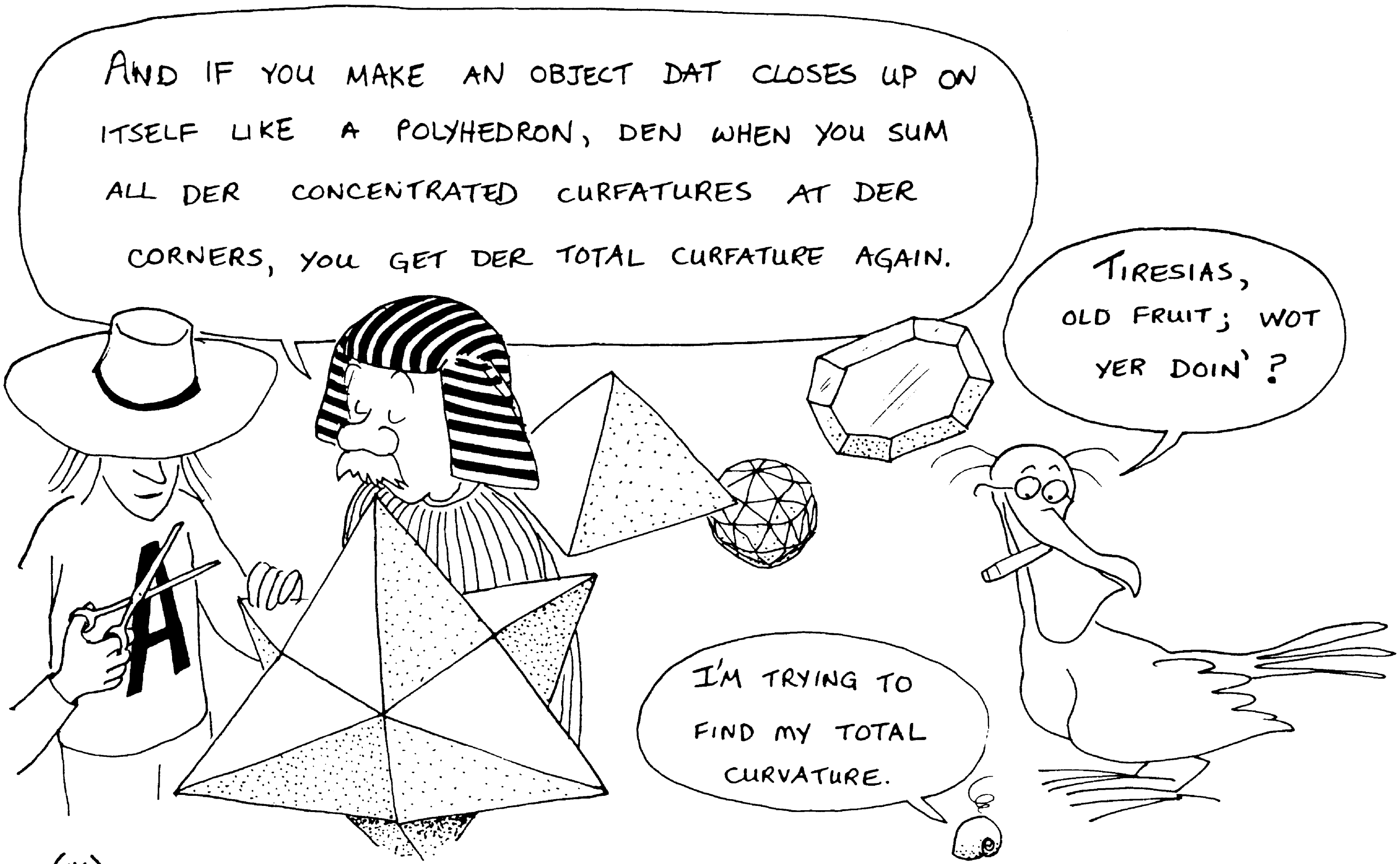
which is correct since all three angles are 90.°



(*) A theorem of Gauss

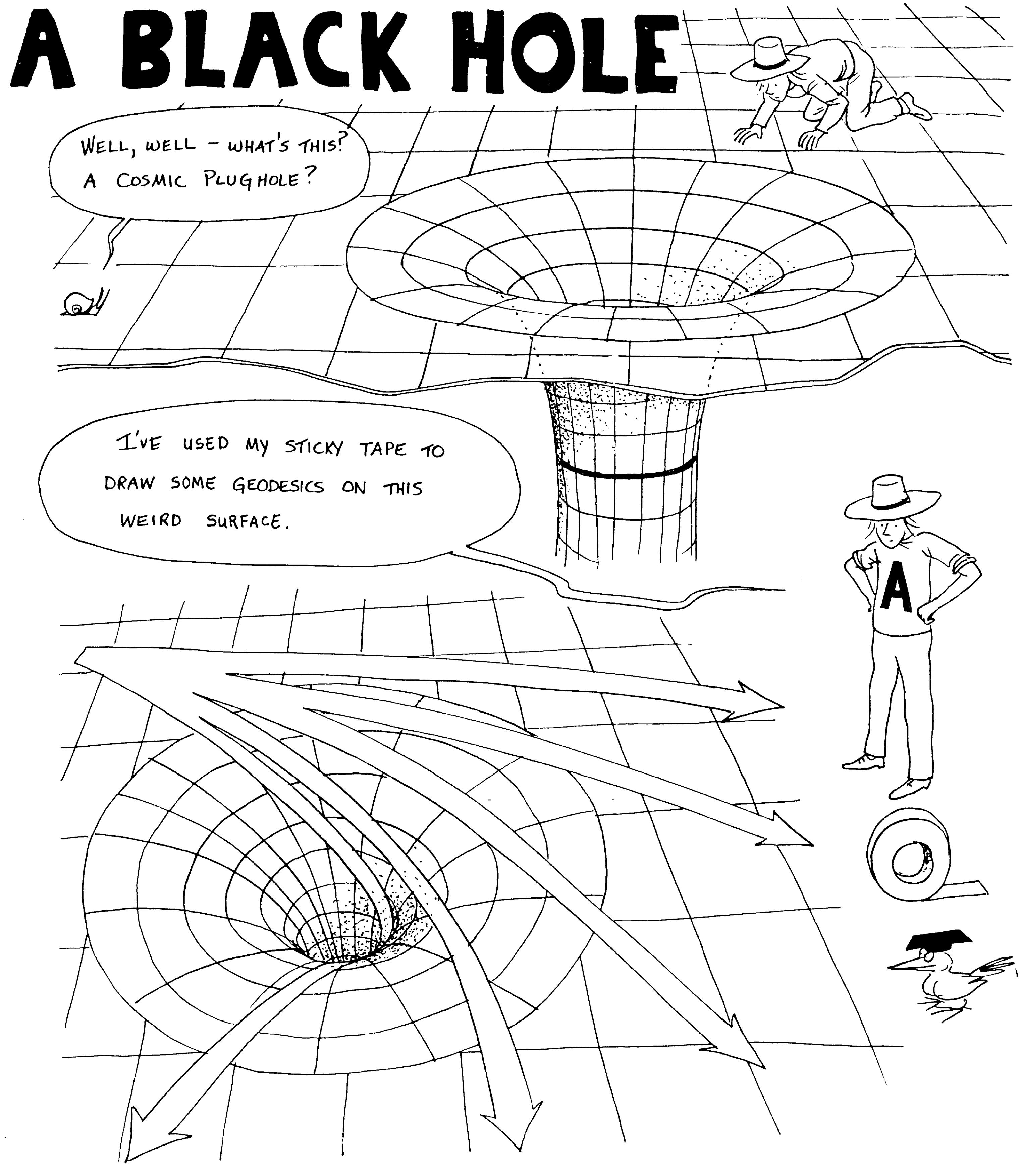


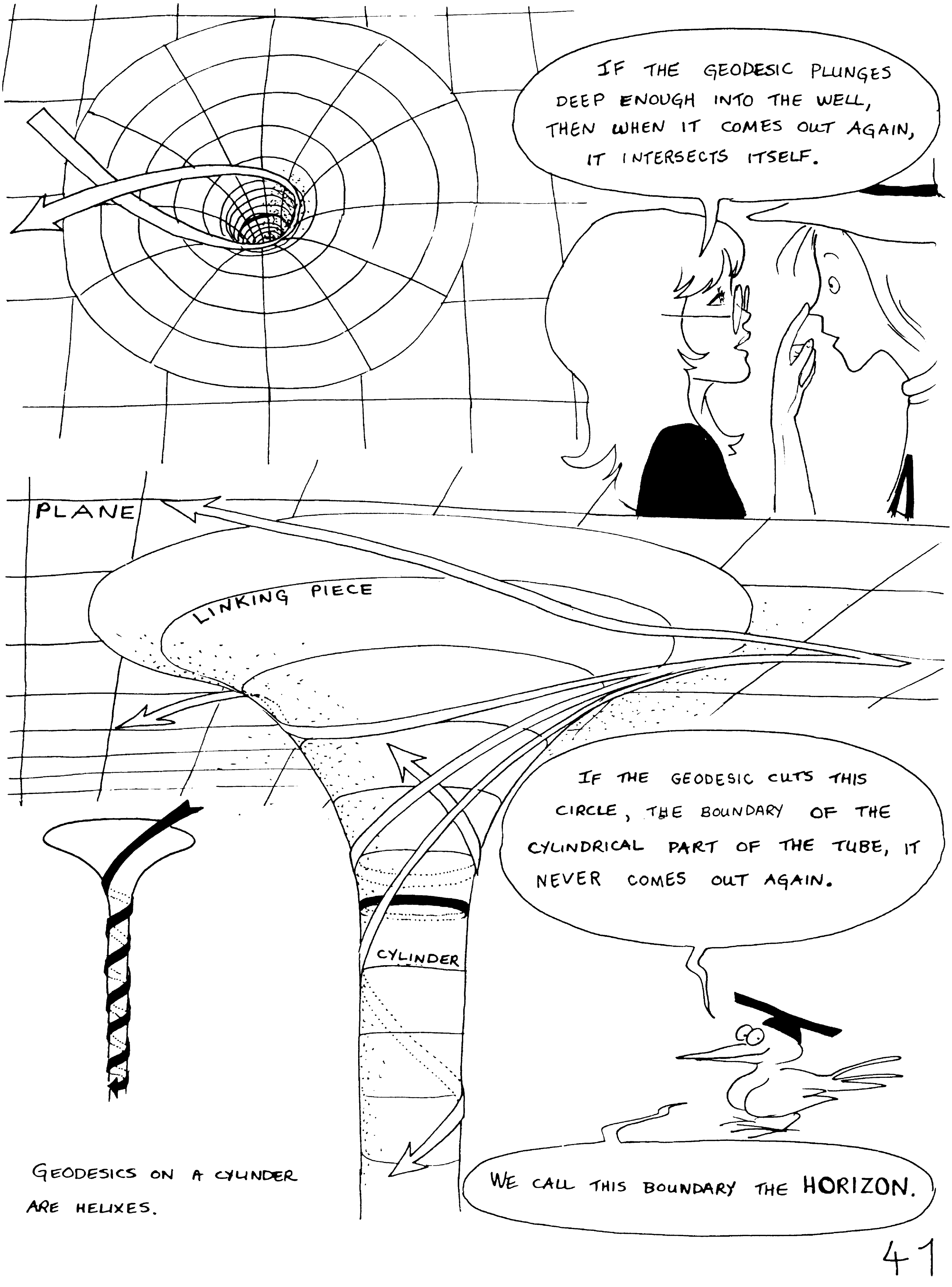
A TORUS WITH N HOLES, A FOUGASSE(*), WILL HAVE A TOTAL CURVATURE OF $-4\pi(N-1)$. YOU LOSE 4π FOR EACH HOLE.

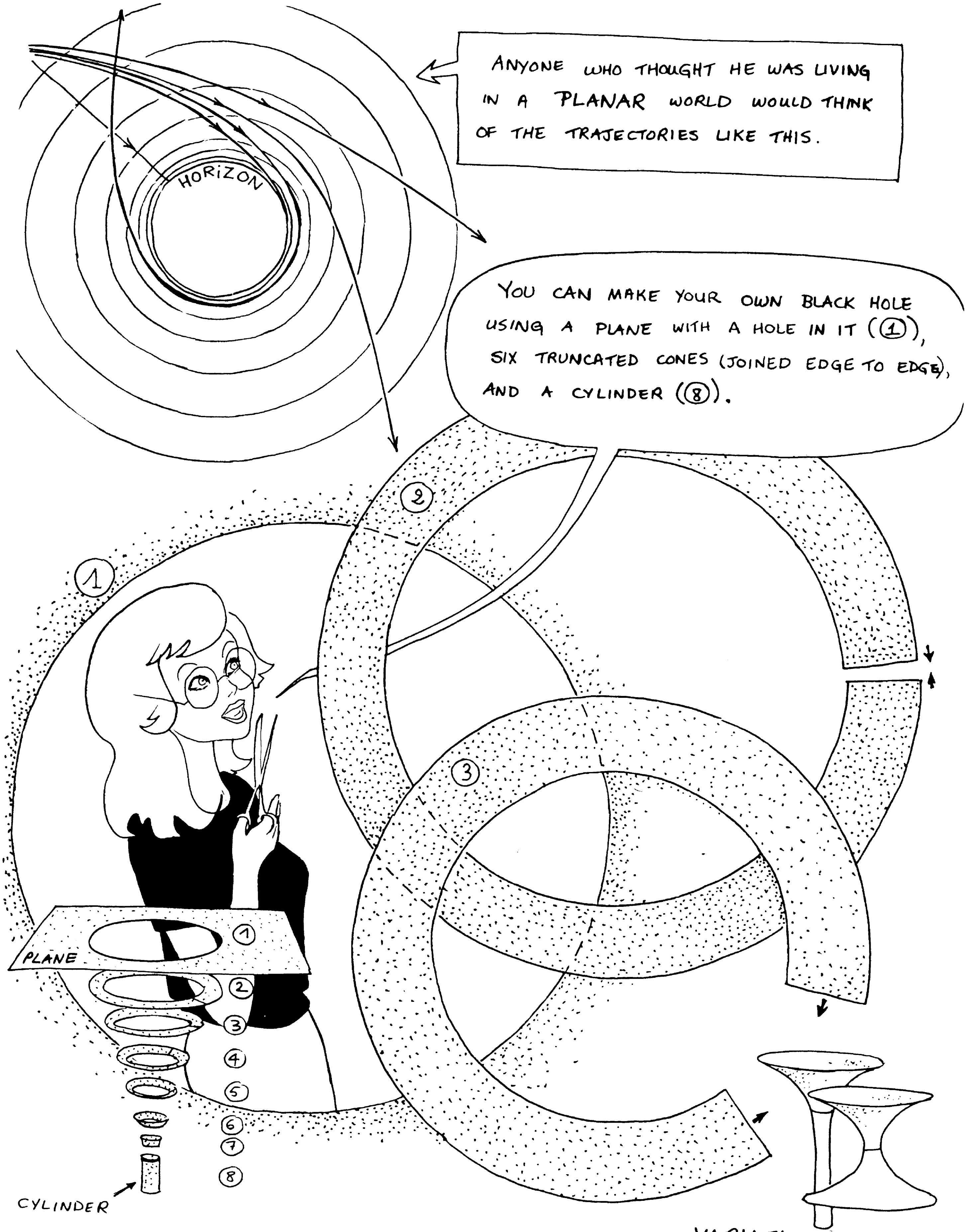


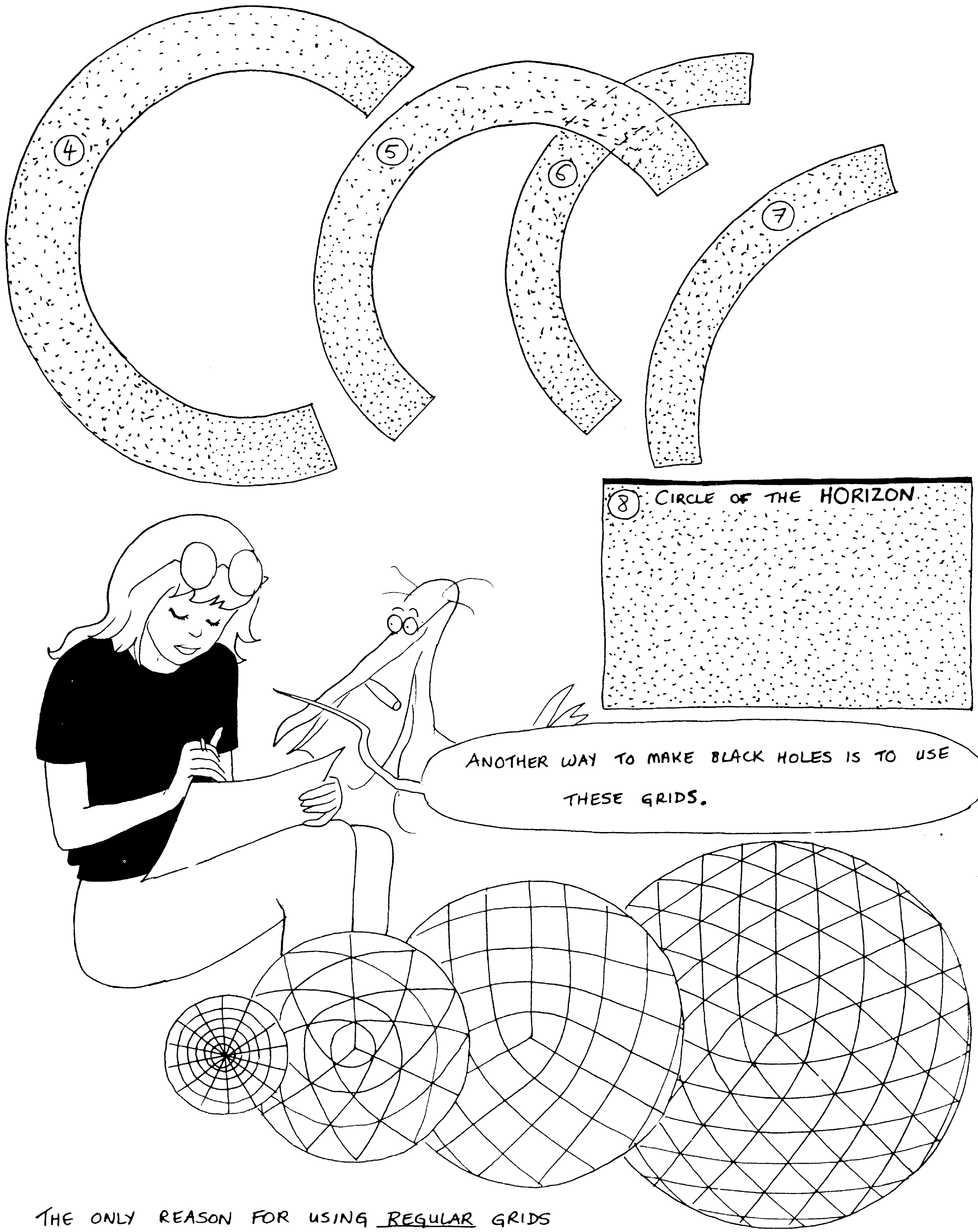
(*) A FOUGASSE IS A SORT OF LOAF MADE IN THE SOUTH OF FRANCE, WHERE THE AUTHOR LIVES.

FIRST ENCOUNTER WITH A BLACK HOLE

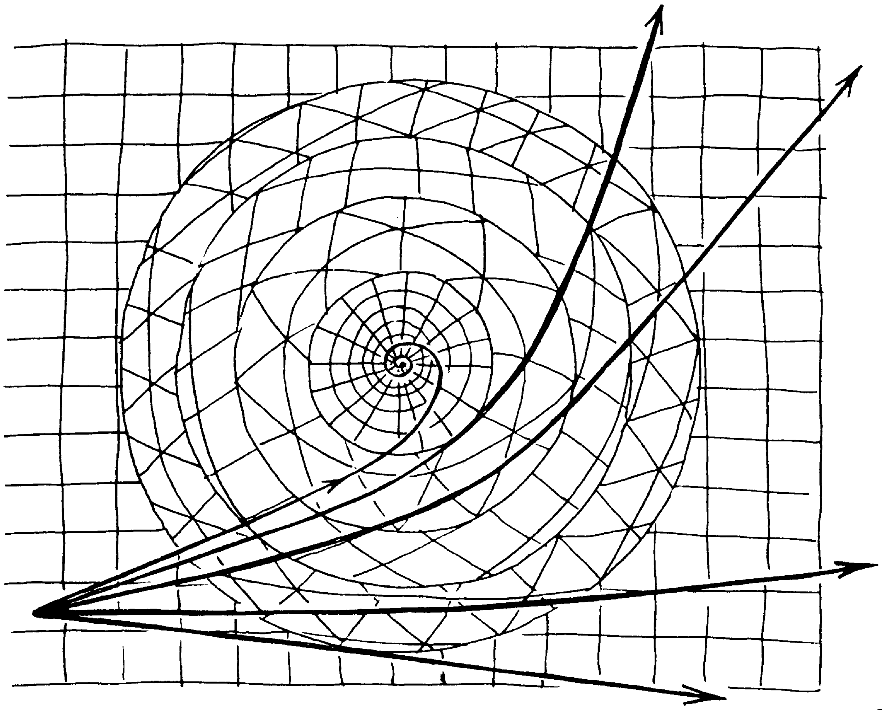



IF THE GEODESIC PLUNGES DEEP ENOUGH INTO THE WELL, THEN WHEN IT COMES OUT AGAIN, IT INTERSECTS ITSELF.
PLANE
LINKING PIECE
CYLINDER
IF THE GEODESIC CUTS THIS CIRCLE, THE BOUNDARY OF THE CYLINDRICAL PART OF THE TUBE, IT NEVER COMES OUT AGAIN.
GEODESICS ON A CYLINDER ARE HELIXES.
WE CALL THIS BOUNDARY THE HORIZON.

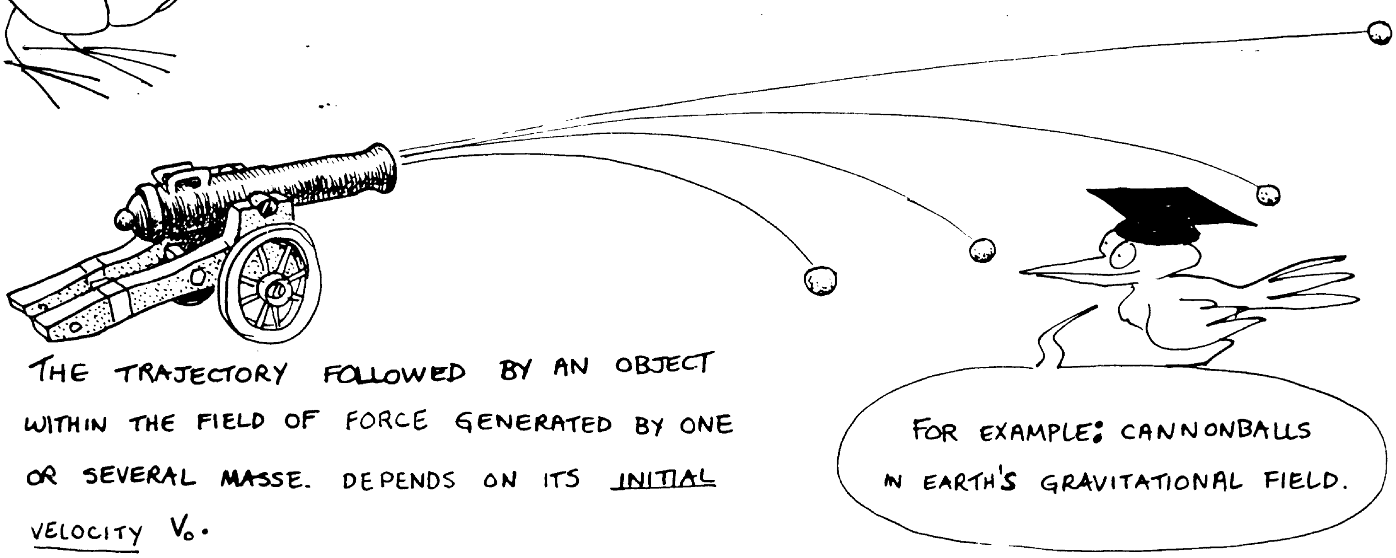

ANYONE WHO THOUGHT HE WAS LIVING IN A PLANAR WORLD WOULD THINK OF THE TRAJECTORIES LIKE THIS.
HORIZON
YOU CAN MAKE YOUR OWN BLACK HOLE USING A PLANE WITH A HOLE IN IT (1), SIX TRUNCATED CONES (JOINED EDGE TO EDGE), AND A CYLINDER (8).
1
2
3
PLANE
1
2
3
4
5
6
7
8
CYLINDER
VARIATIONS



THE ONLY REASON FOR USING REGULAR GRIDS IS TO MAKE THE RESULT LOOK PRETTY.

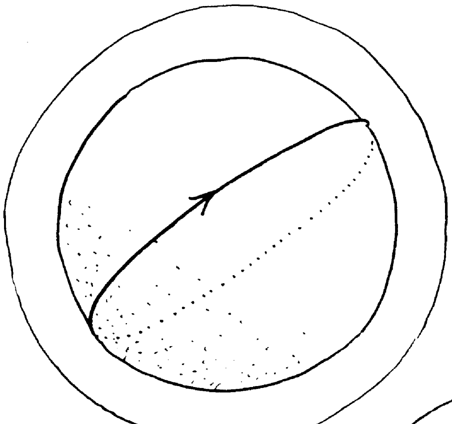


RULES OF THE GAME: YOU MUST DRAW LINES THAT CUT EACH GRID AT A FIXED ANGLE, WHILE MAINTAINING CONSISTENCY AND CONTINUITY AT EACH BOUNDARY CIRCLE WHERE THE GRIDS JOIN UP. THE CLOSER YOU APPROACH THE BLACK HOLE, THE STRONGER ITS ATTRACTION WILL SEEM. WITHIN THE HORIZON CIRCLE THE TRAJECTORY WILL ROLL UP INTO A SPIRAL. NOTE THAT THE CENTRAL GRID, WHICH IS POLE-SHAPED, CAN BE OBTAINED FROM A GRID OF GEODESICS ON THE CYLINDER, VIEWED IN PERSPECTIVE.

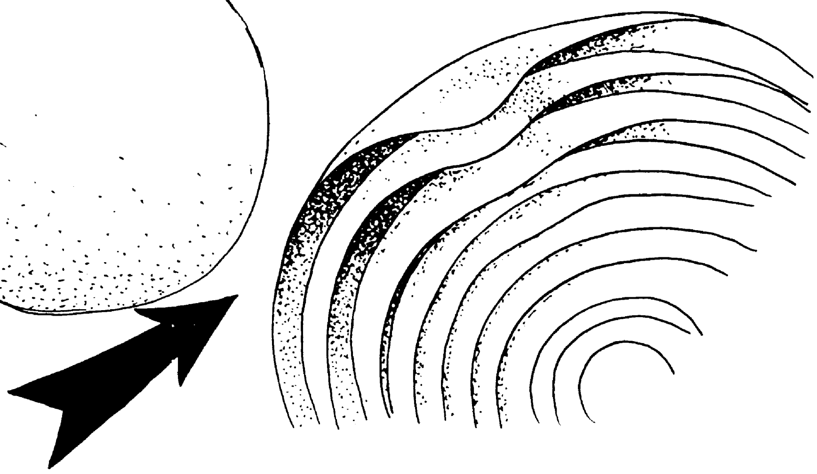


THE TRAJECTORY FOLLOWED BY AN OBJECT WITHIN THE FIELD OF FORCE GENERATED BY ONE OR SEVERAL MASSE. DEPENDS ON ITS INITIAL VELOCITY V_0.

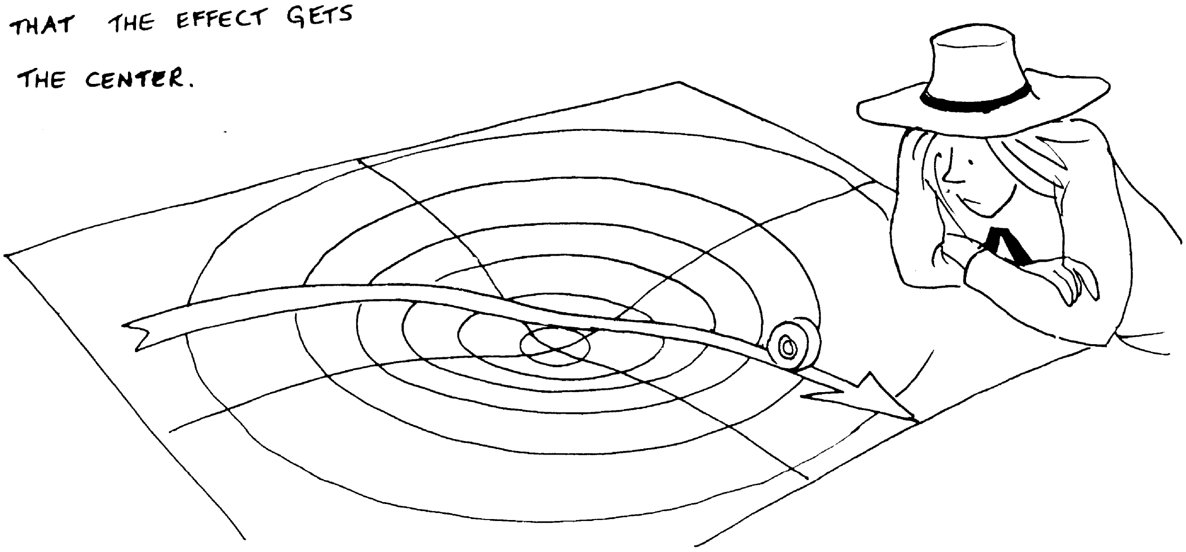
(*) THIS MODEL HAS BEEN INTRODUCED IN EVERYTHING IS RELATIVE (SAME SERIES) UNDER THE NAME COSMIC PARK.



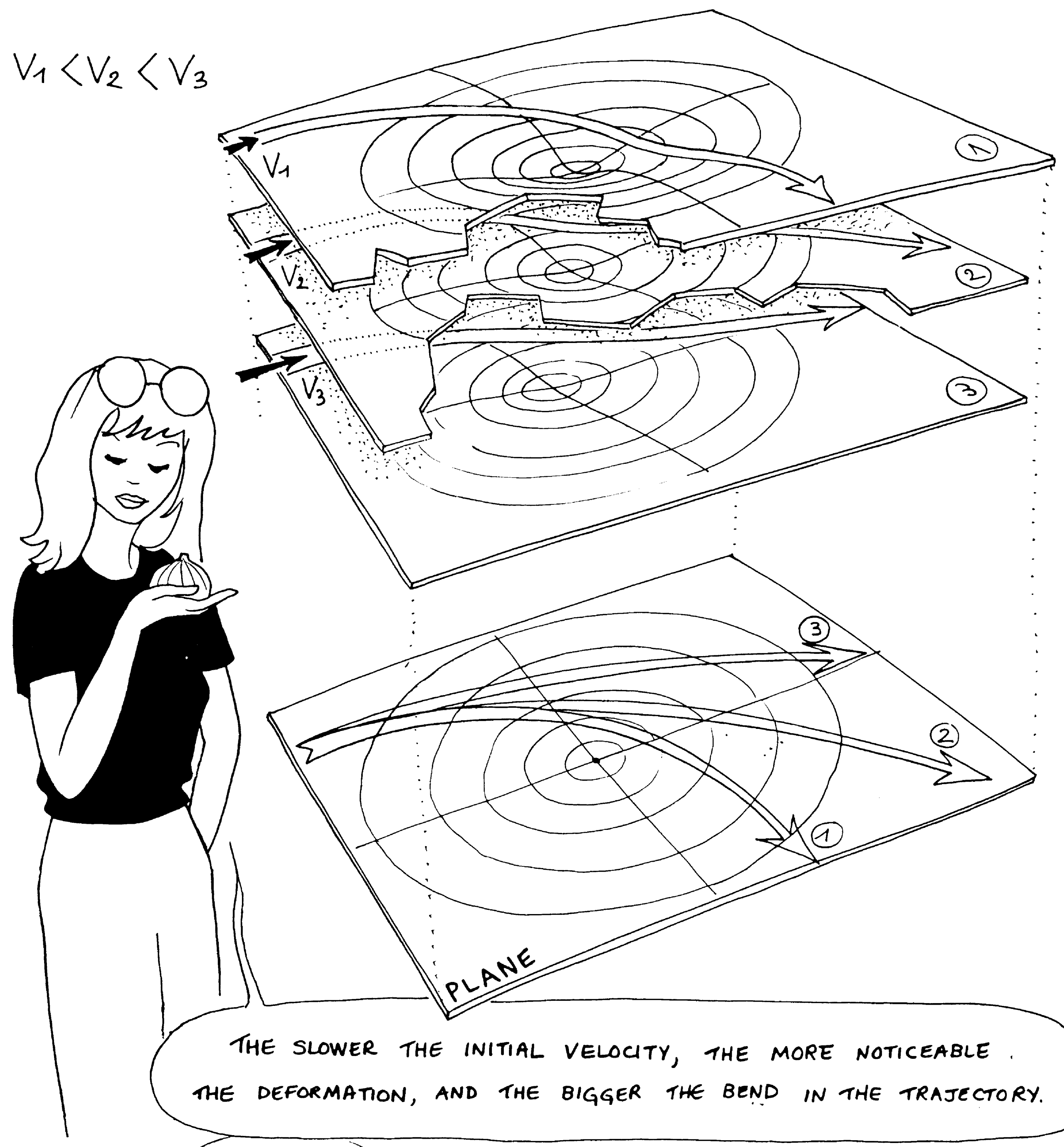
IF THERE ARE NO **FORCES**, THEN THE SPEED OF THE OBJECT DOESN'T CHANGE. SO IT STAYS ON A **SPHERE**, ALWAYS THE SAME DISTANCE FROM THE CENTER OF THE ONION. IT FOLLOWS A GEODESIC, THAT IS, A **GREAT CIRCLE**, ON THIS SPHERE.

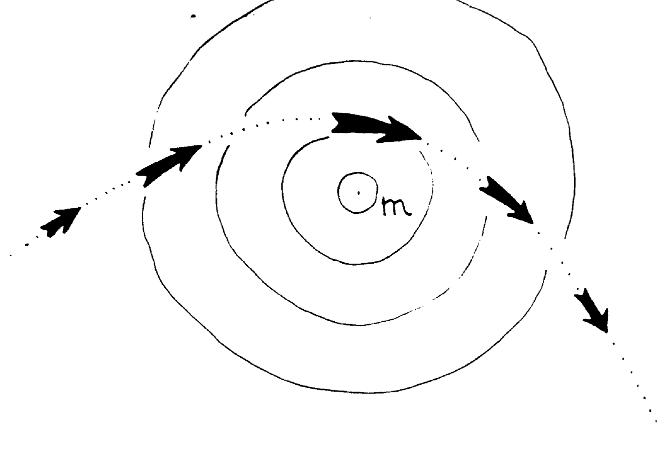


WHEN MR. ALBERT HIT IT WITH HIS HAMMER, THIS IS WHAT HAPPENED. YOU CAN SEE THAT THE EFFECT GETS LESS NEARER THE CENTER.



HERE IS A **DENT** (OR A **BUMP**, IT MAKES NO DIFFERENCE). THE CONTOUR LEVELS (WHICH ARE **NOT** GEODESICS!) HAVE BEEN DRAWN, ALONG WITH ONE SELECTED GEODESIC.





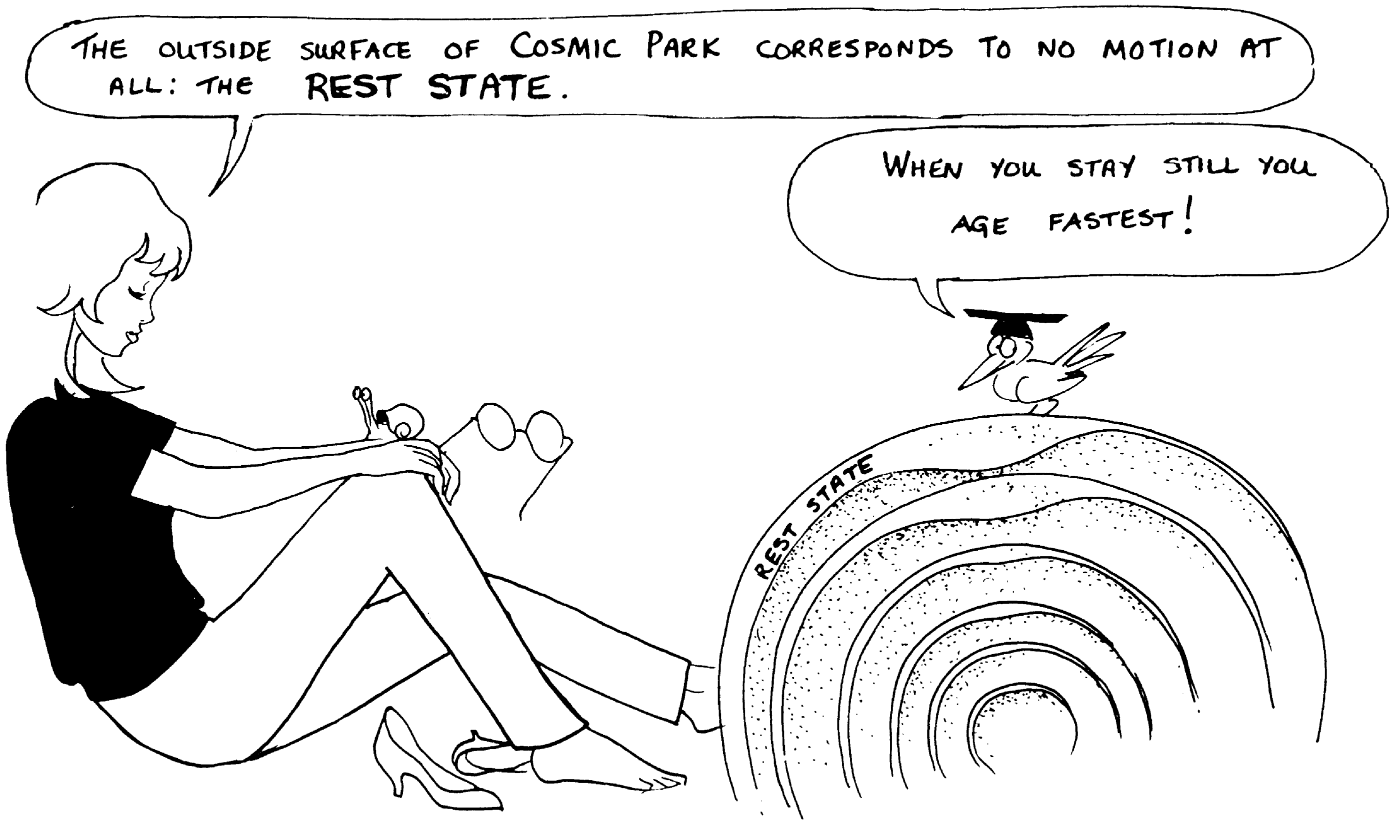
UNDER THE INFLUENCE OF GRAVITATIONAL ATTRACTION, THE SPEED OF AN OBJECT FIRST INCREASES, THEN DECREASES. IT IS GREATEST WHEN THE DISTANCE BETWEEN THE OBJECT AND THE ATTRACTING MASS IS SMALLEST. ASTRONOMERS CALL THIS POSITION PERIHELION.


THAT'S A GOOFY LOOKING GADGET!
IT'S A CHRONOSCAPHE.
IT LETS YOU FOLLOW GEODESICS IN COSMIC PARK.
WHY SHUT YOURSELF UP IN A CHRONOSCAPHE?
THE WHOLE OF COSMIC PARK IS FILLED WITH A FLUID: CHRONOL.
YER'LL NEVER GET ME IN ONE O' THOSE FINGS!
THE PATH OF A CHRONOSCAPHE IS CALLED DESTINY, LENNY...

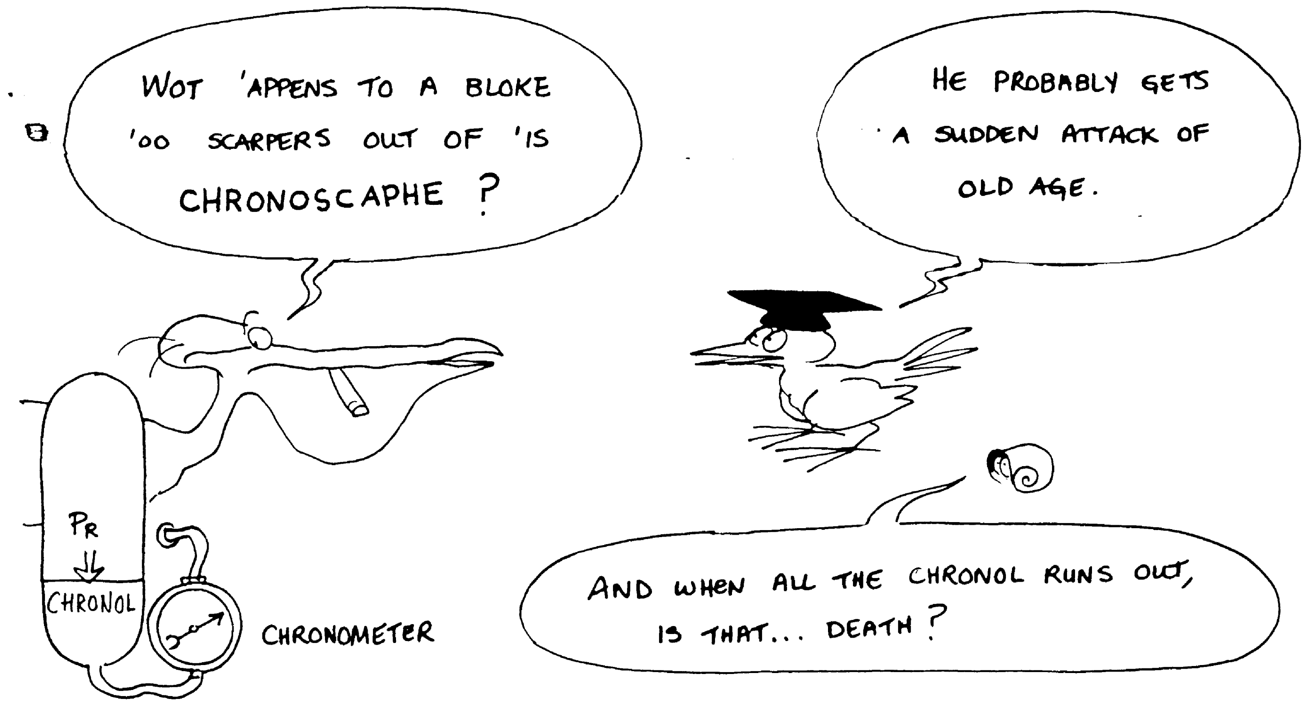
(*) MEMO: THE SECOND PRINCIPLE OF THERMODYNAMICS SAYS THAT IT IS IMPOSSIBLE TO FOLLOW THE GEODESICS OF SPACE-TIME (COSMIC PARK) IN THE REVERSE DIRECTION.

The Boss

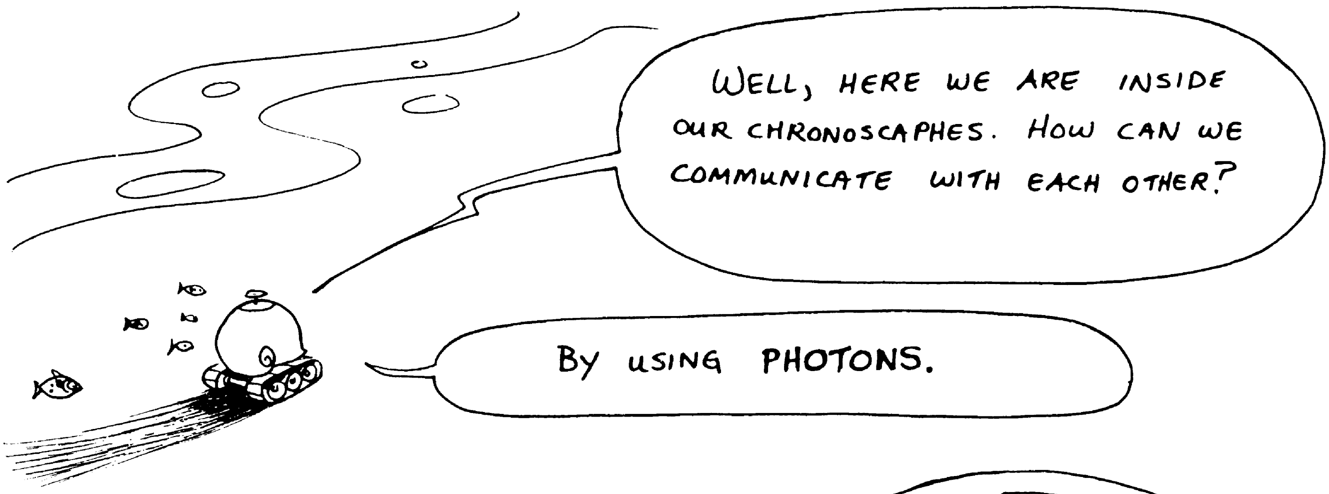
(*) SEE **EVERYTHING IS RELATIVE**, SAME SERIES.



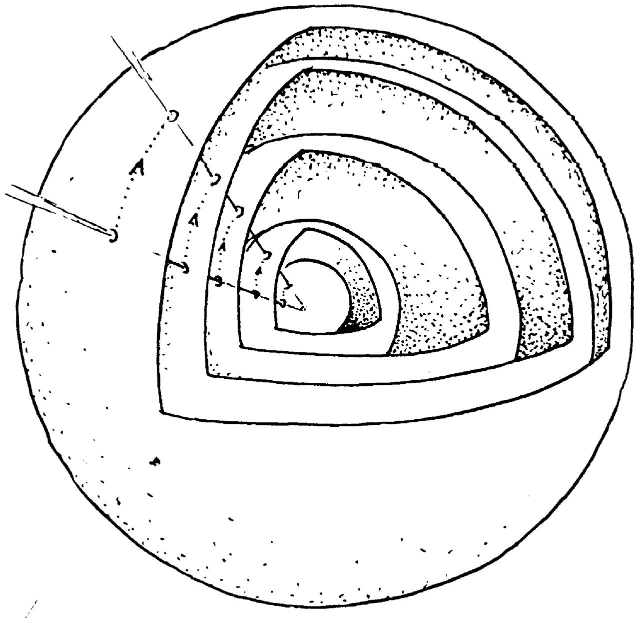
A VERY MASSIVE BODY PRODUCES A LARGE AMOUNT OF CURVATURE IN SPACE-TIME. THIS MEANS THAT ANY NEARBY OBJECT, EVEN ONE AT REST, IS IMMERSED IN CHRONOL AT A HIGHER PRESSURE. SO, FOR IT, TIME FLOWS MORE SLOWLY THAN IT WOULD FOR AN OBJECT AT REST, BUT FAR FROM ANY MASS. THIS SLOWING DOWN OF TIME HAPPENS, FOR INSTANCE, NEAR A SUPERDENSE OBJECT SUCH AS A NEUTRON STAR.

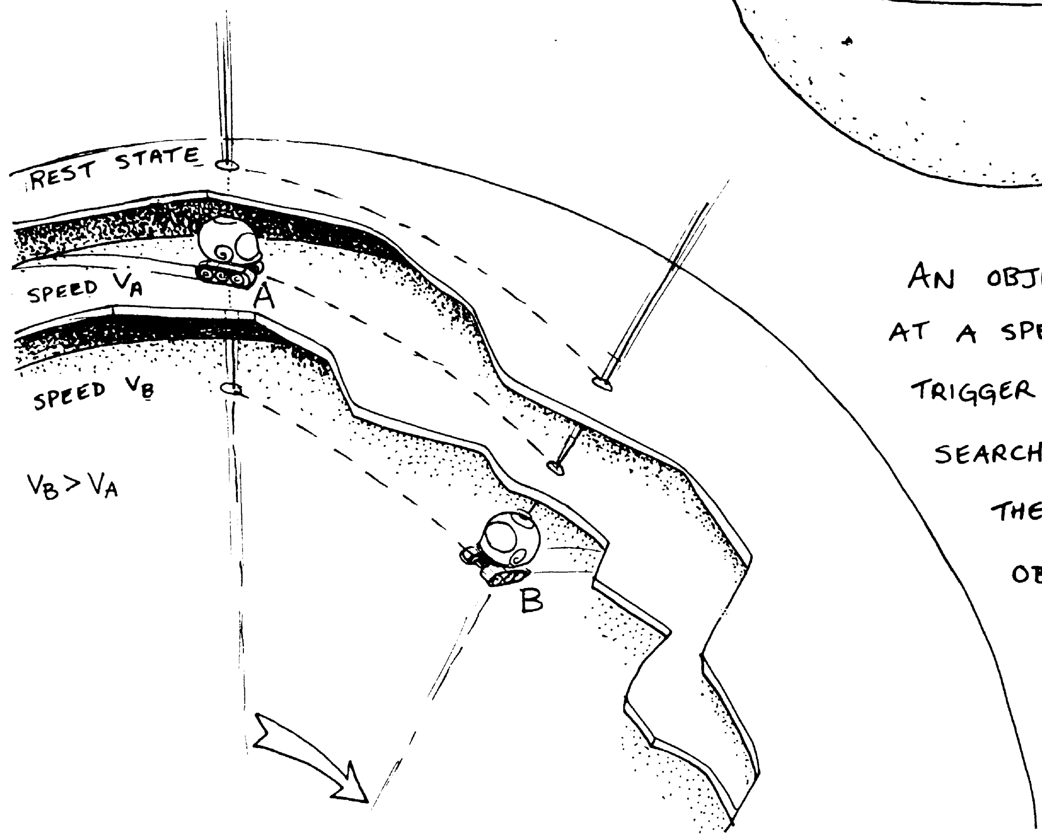


COMMUNICATION

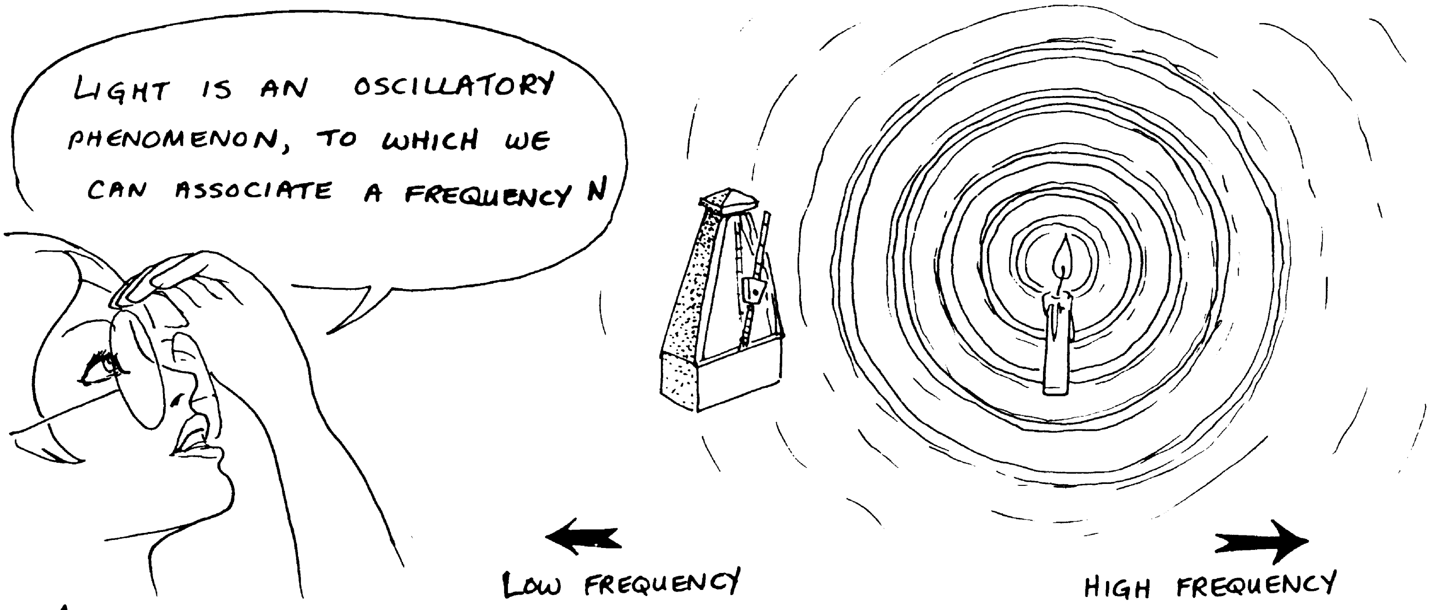


PHOTONS – TINY QUANTITIES OF LIGHT— BEHAVE JUST LIKE A SEARCHLIGHT BEAM, SWEEPING ACROSS ALL THE LAYERS OF COSMIC PARK AT A CONSTANT ANGULAR VELOCITY.



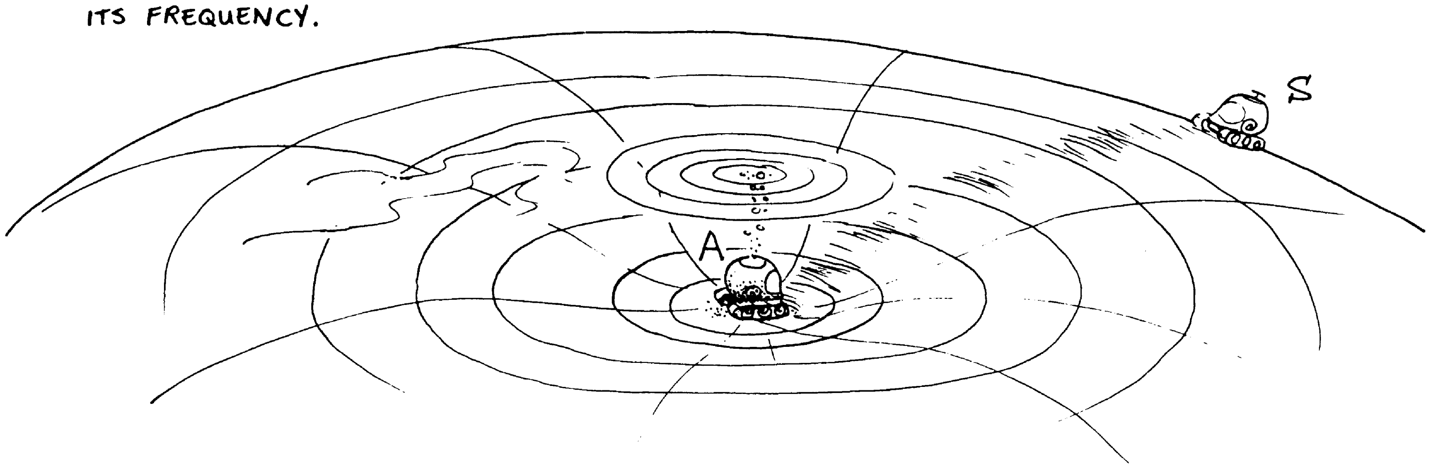


AN OBJECT A, TRAVELING AT A SPEED V_A, CAN TRIGGER OFF ONE OF THESE SEARCHLIGHT BEAMS IN THE DIRECTION OF AN OBJECT B, MOVING AT A SPEED V_B.



AND ITS COLOR IS DETERMINED BY ITS FREQUENCY.

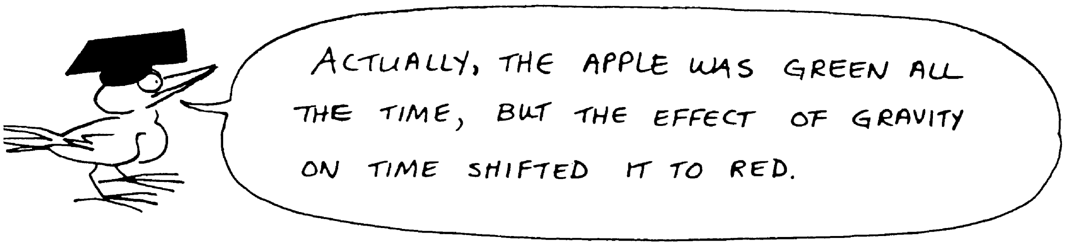
INFRARED RED ORANGE YELLOW GREEN BLUE VIOLET ULTRAVIOLET



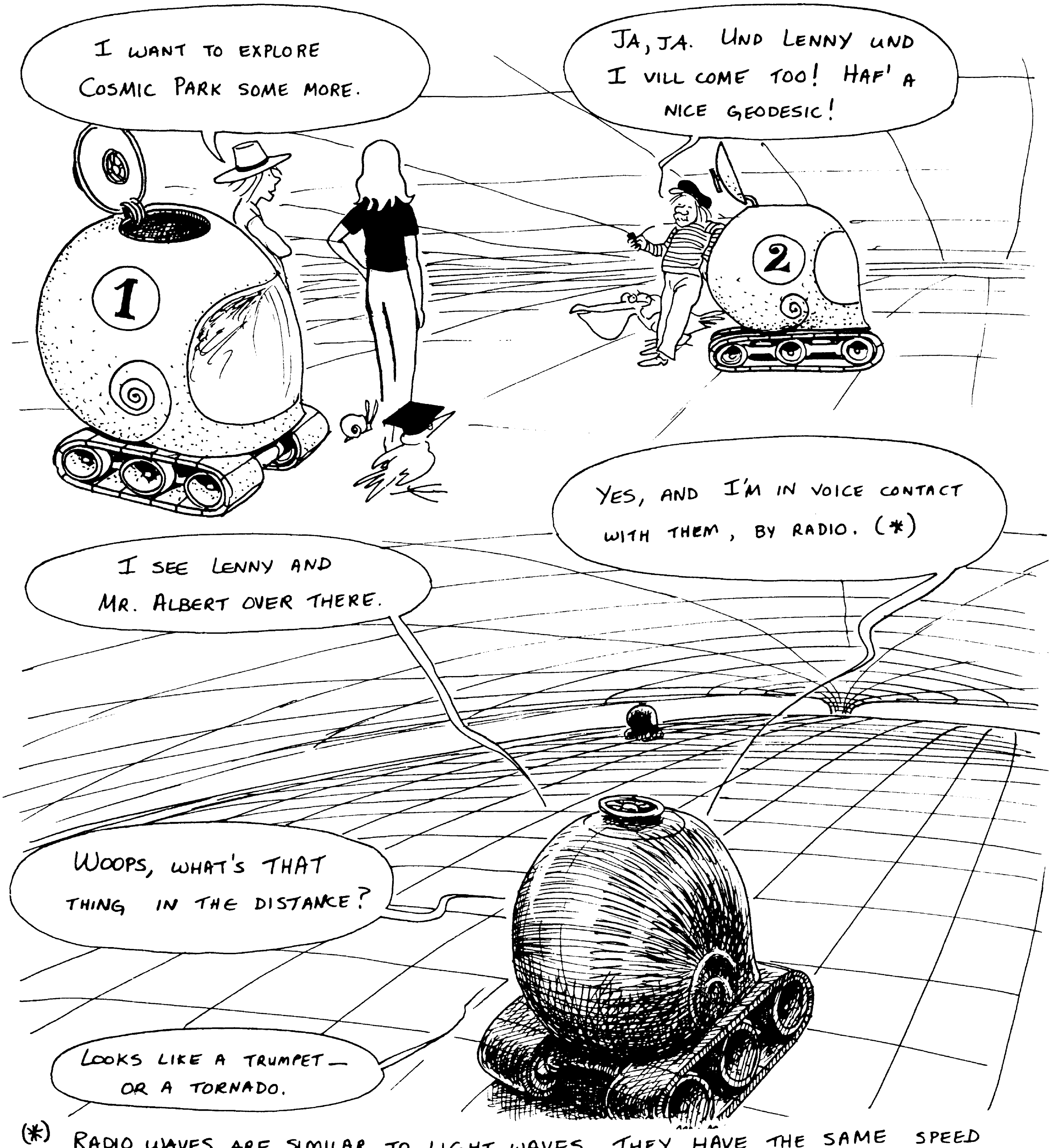
THE FREQUENCIES OF THE PHOTONS EMITTED OR RECEIVED WILL BE MEASURED RELATIVE TO THE FLOW-RATE OF TIME IN THE CHRONOSCAPHE OF THE EMITTER OR RECEIVER. IN CHRONOSCAPHE A, ARCHIE SENDS OUT BLUE LIGHT. HE HAPPENS TO BE IN A REGION OF SPACE THAT IS HIGHLY CURVED – FOR EXAMPLE HE MAY BE NEAR A NEUTRON STAR OF ENORMOUS MASS.

SOPHIE, IN CHRONOSCAPHE S, RECEIVES THIS LIGHT. SHE IS A LONG WAY FROM THE SUPERDENSE OBJECT. SO HER TIME FLOWS FASTER, AND SHE MEASURES A LOWER FREQUENCY. TO HER, THE COLOR OF THE LIGHT SEEMS TO HAVE SHIFTED TOWARDS RED.

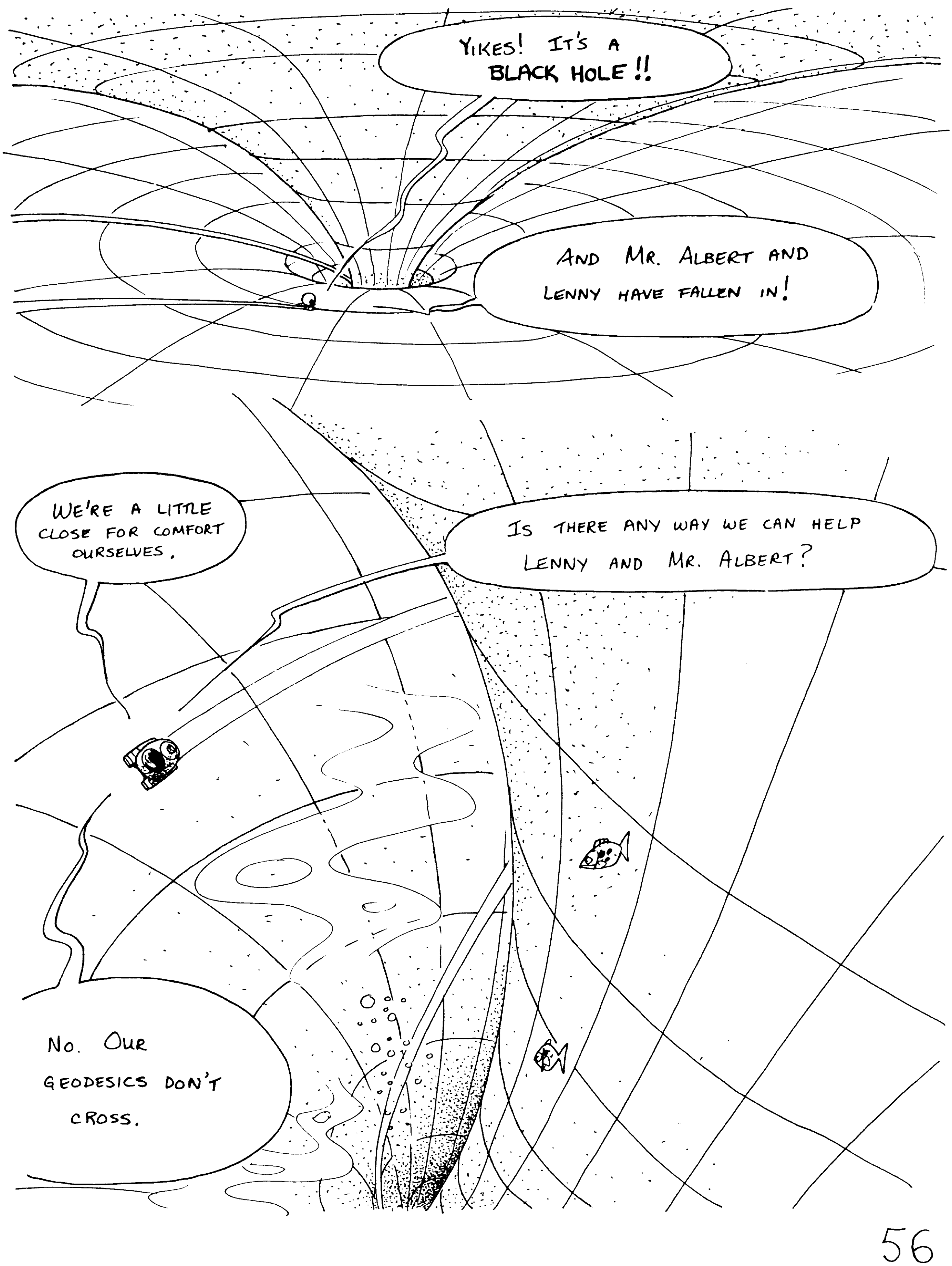
ARCHIE IS STANDING ON A NEUTRON STAR. (WE HAVE TEMPORARILY SUSPENDED THE EFFECTS OF GRAVITY ON HIS BODY, SINCE THAT WOULD INSTANTLY SPREAD HIM OUT FLATTER THAN A PANCAKE.)



SECOND ENCOUNTER WITH A BLACK HOLE



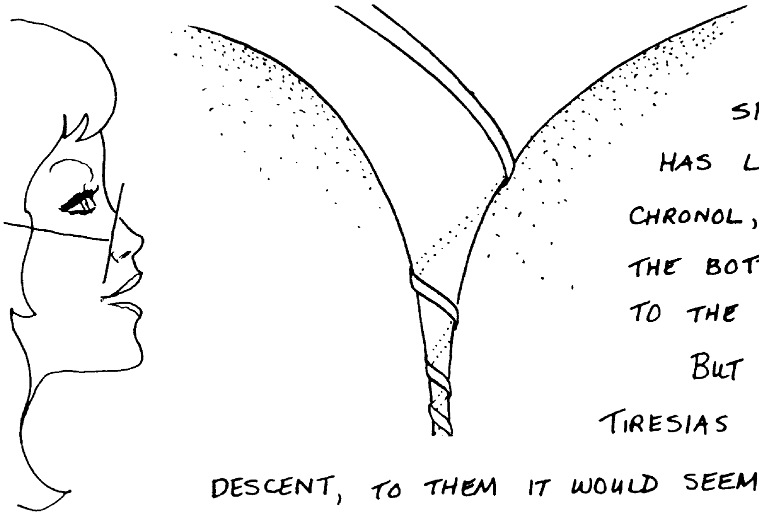
(*) RADIO WAVES ARE SIMILAR TO LIGHT WAVES. THEY HAVE THE SAME SPEED OF PROPAGATION C, BUT LOWER FREQUENCY.


YIKES! IT'S A BLACK HOLE!!
AND MR. ALBERT AND LENNY HAVE FALLEN IN!
WE'RE A LITTLE CLOSE FOR COMFORT OURSELVES.
IS THERE ANY WAY WE CAN HELP LENNY AND MR. ALBERT?
NO. OUR GEODESICS DON'T CROSS.


CAN YOU SEE THEM?
THE BOTTOM OF THE BLACK HOLE IS TOTALLY OPAQUE.
I CAN STILL SEE THEM, BUT THEIR CHRONOSCAPHE HAS GONE A DULL ORANGE COLOR.
HALLO? MR. ALBERT? LENNY? ARE YOU RECEIVING ME?
IT'S BAFFLIN'! 'IS VOICE 'AS GORN SQUEAKY AN' 'E'S TALKIN' TOO QUICK. SOUNDS LIKE DONALD DUCK.
HIS VOICE IS GETTING DEEPER AND DEEPER, LIKE A RECORD SLOWING DOWN!
AHHDTEUHHH...
THERE ARE COMMUNICATION PROBLEMS WHEN YOU LIVE IN VERY DIFFERENT "TIME ZONES."

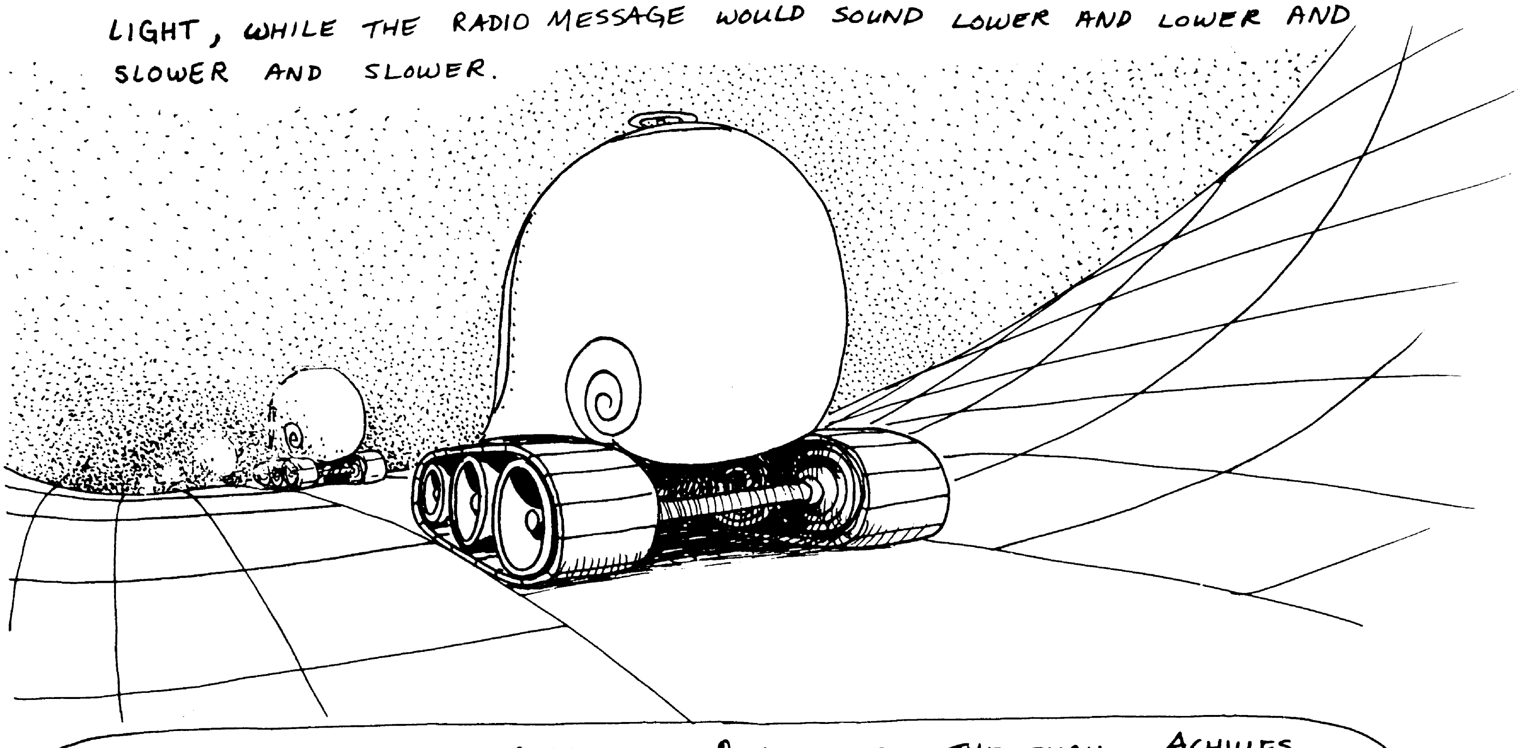
A MATTER OF TIME

THE DEEPER MR. ALBERT AND LENNY SINK INTO THE CHRONOL, THE MORE THE OUTSIDE PRESSURE P_E INCREASES, THE SLOWER THE CLEPSYDRA RUNS OUT OF CHRONOL, AND THE SLOWER TIME FLOWS IN THEIR CHRONOSCAPHE.



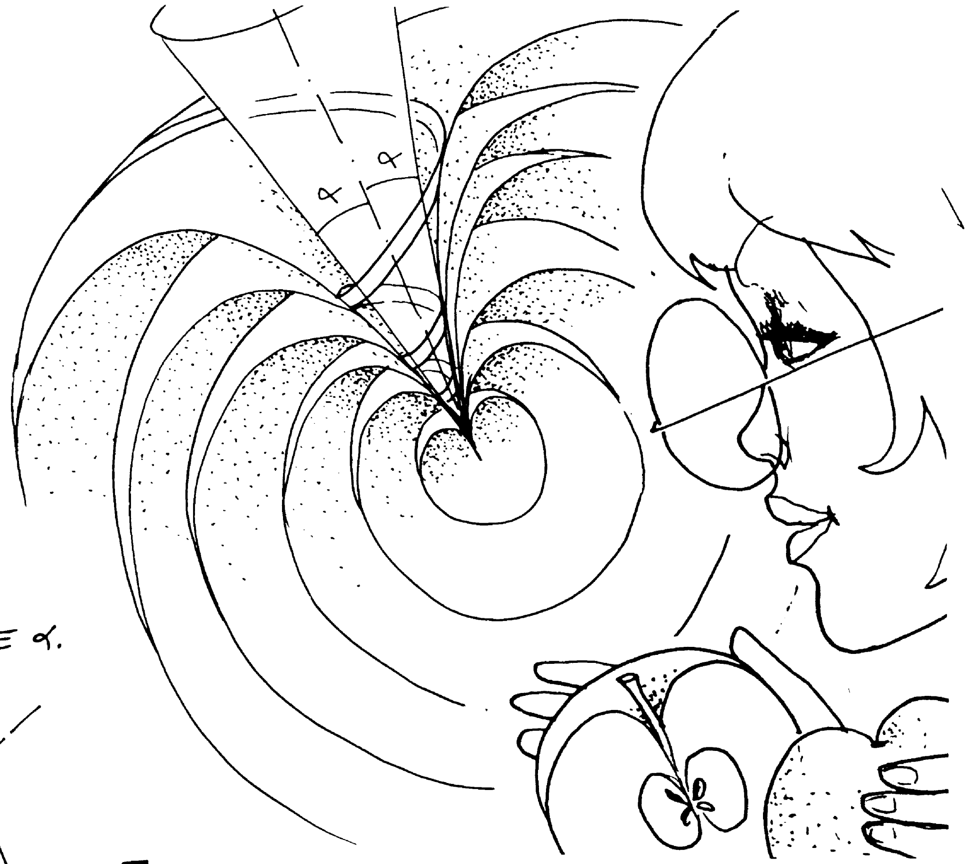
WHEN THEY GET DOWN TO THE BOTTOM OF THINGS, AT THE SPEED OF LIGHT, THEIR WATER-CLOCK HAS LOST ONLY A LIMITED AMOUNT OF CHRONOL, WHICH MEANS THAT THEY REACH THE BOTTOM IN A <u>FINITE</u> TIME, ACCORDING TO THE TIME FLOWING IN THEIR OWN CHRONOSCAPHE.

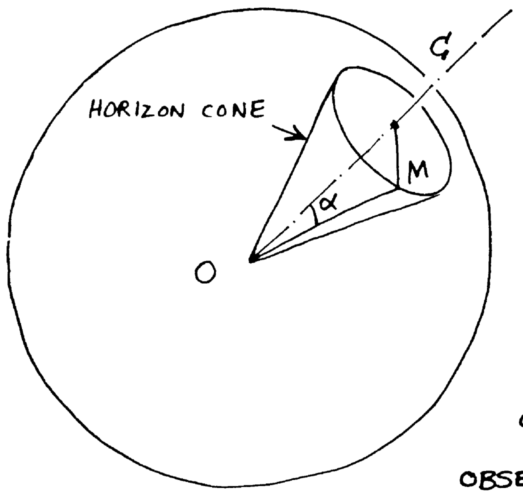
BUT IF SOPHIE, ARCHIE, MAX, AND TIRESIAS COULD CONTINUE TO TRACK THEIR DESCENT, TO THEM IT WOULD SEEM INTERMINABLE. THE LIGHT EMITTED BY THE CHRONOSCAPHE WOULD DROP DEEP INTO THE INFRARED, BELOW THE RANGE OF VISIBLE LIGHT, WHILE THE RADIO MESSAGE WOULD SOUND LOWER AND LOWER AND SLOWER AND SLOWER.



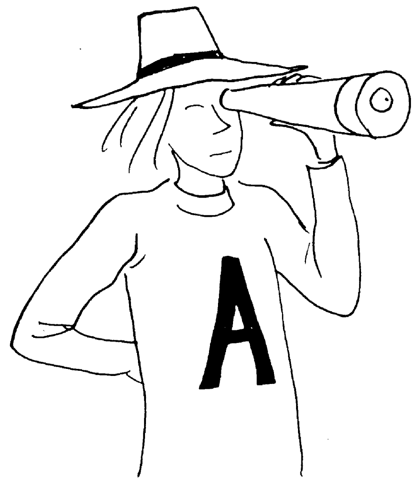
IT REMINDS ME OF THE PARADOX OF ACHILLES AND THE SNAIL. ACHILLES TRIES TO CATCH THE SNAIL, BY REPEATEDLY HALVING THE DISTANCE BETWEEN THEM. YOU'D THINK IT WOULD GO ON FOREVER, BUT THE STEPS ADD UP TO A <u>FINITE</u> TOTAL TIME.

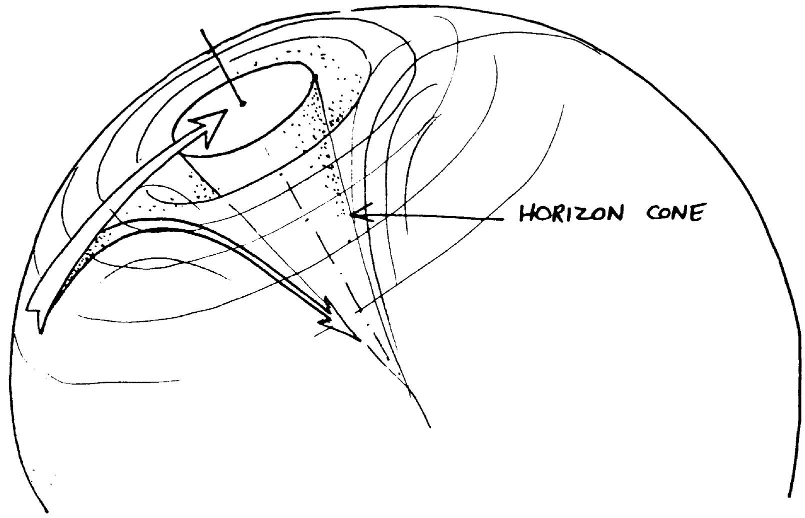
HERE IS A PICTURE OF A BLACK HOLE, ACCORDING TO THE COSMIC PARK MODEL. THE SPIKE HAS PENETRATED ALL THE WAY TO THE CENTER OF SPACE-TIME, WHERE THE SPEED IS THAT OF LIGHT. ALL THE LAYERS HAVE BECOME TANGENT TO A CONE WITH VERTEX SEMI-ANGLE α.

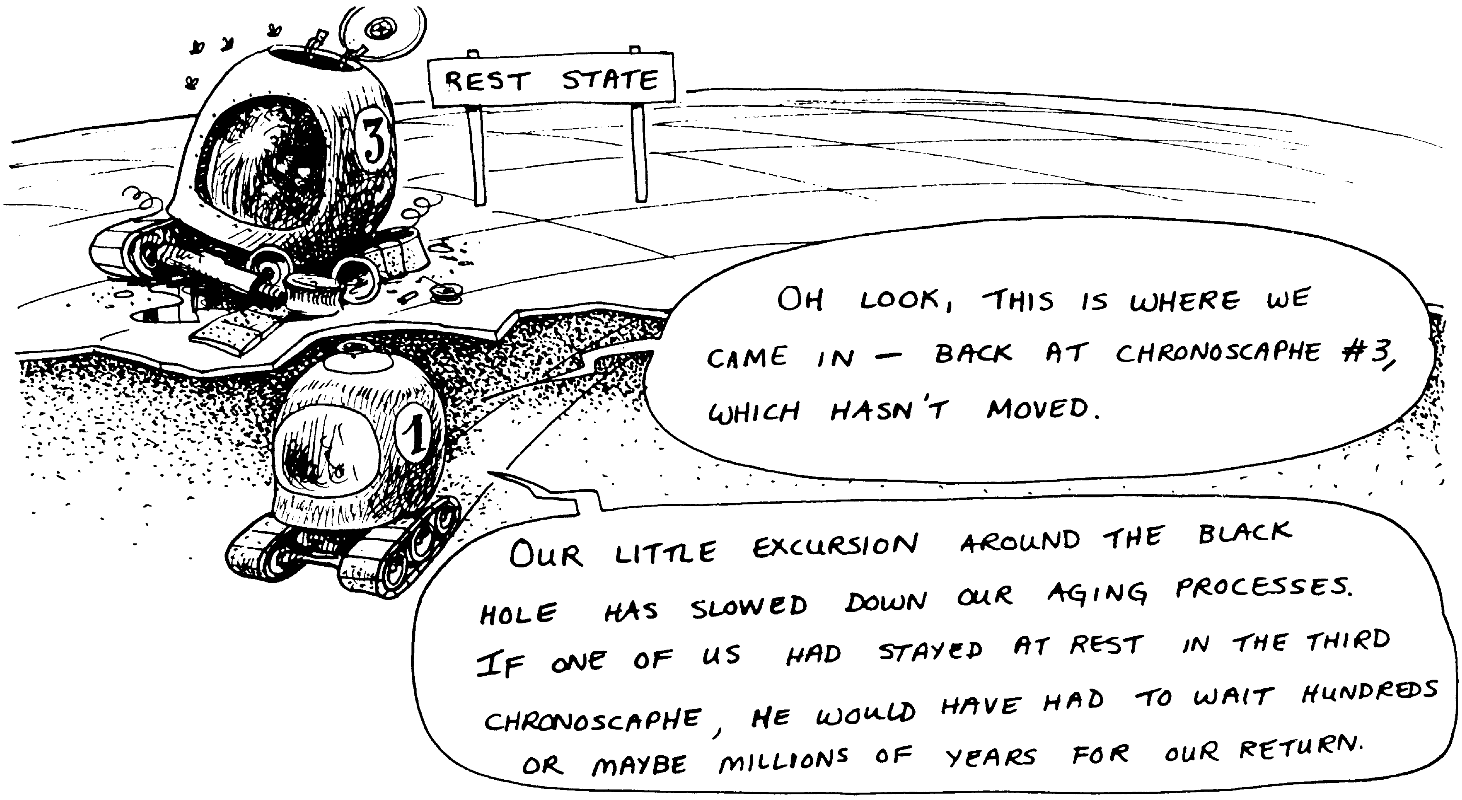


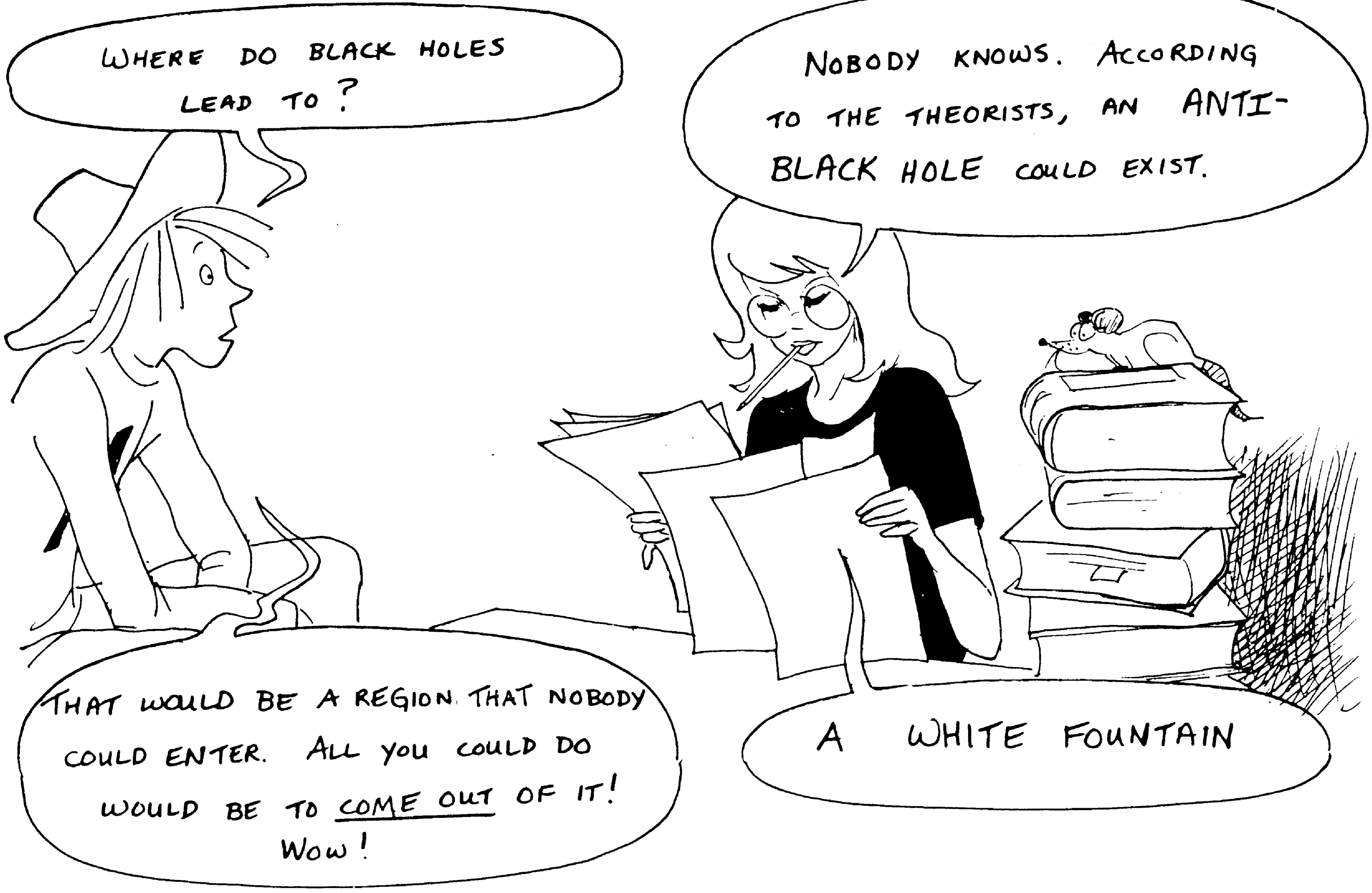


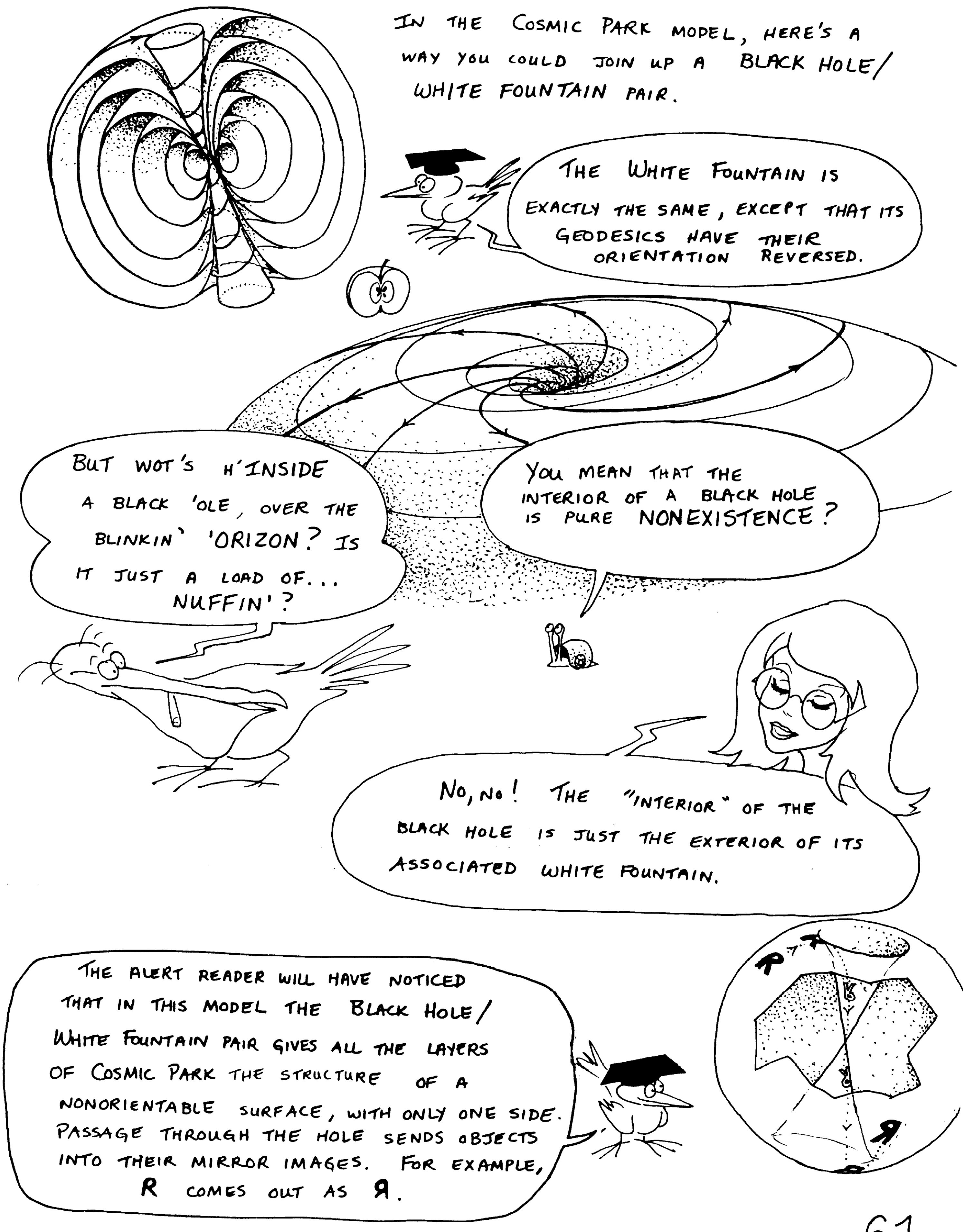
IN THIS MODEL, DISTANCE IS ACTUALLY AN ANGLE BETWEEN TWO RADIAL VECTORS, SUCH AS $\overrightarrow{OM}$ AND $\overrightarrow{OC}$. FROM THE DIAGRAM ABOVE YOU CAN SEE THAT NOTHING CAN PENETRATE INSIDE THIS CONE WITH SEMI-ANGLE α. IMAGINE AN OBSERVER IN A REST STATE AT THE SURFACE OF THE CHRONOL, WHO DOESN'T REALIZE SPACE-TIME IS CURVED. TO HIM, THE FRONTIER OF THE BLACK HOLE - THE **EVENT HORIZON** - LOOKS LIKE A **CIRCLE**, WHICH IS REACHED AT THE SPEED OF LIGHT.






REST STATE
OH LOOK, THIS IS WHERE WE CAME IN — BACK AT CHRONOSCAPHE #3, WHICH HASN'T MOVED.
OUR LITTLE EXCURSION AROUND THE BLACK HOLE HAS SLOWED DOWN OUR AGING PROCESSES. IF ONE OF US HAD STAYED AT REST IN THE THIRD CHRONOSCAPHE, HE WOULD HAVE HAD TO WAIT HUNDREDS OR MAYBE MILLIONS OF YEARS FOR OUR RETURN.


WHERE DO BLACK HOLES LEAD TO?
NOBODY KNOWS. ACCORDING TO THE THEORISTS, AN ANTI-BLACK HOLE COULD EXIST.
A WHITE FOUNTAIN
THAT WOULD BE A REGION THAT NOBODY COULD ENTER. ALL YOU COULD DO WOULD BE TO COME OUT OF IT! WOW!

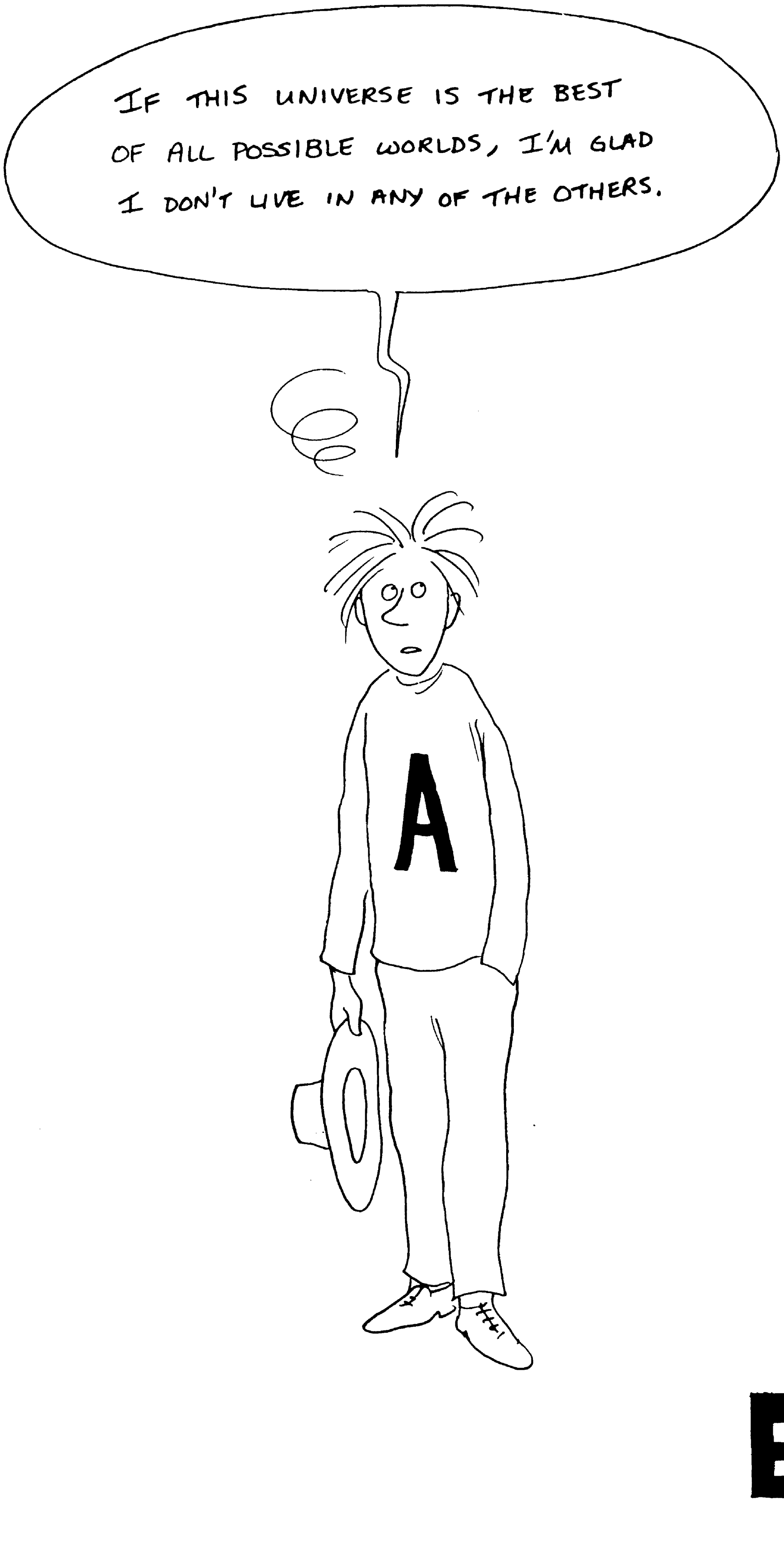

IN THE COSMIC PARK MODEL, HERE'S A WAY YOU COULD JOIN UP A BLACK HOLE/ WHITE FOUNTAIN PAIR.
THE WHITE FOUNTAIN IS EXACTLY THE SAME, EXCEPT THAT ITS GEODESICS HAVE THEIR ORIENTATION REVERSED.
BUT WOT'S H'INSIDE A BLACK 'OLE, OVER THE BLINKIN' 'ORIZON? IS IT JUST A LOAD OF... NUFFIN'?
YOU MEAN THAT THE INTERIOR OF A BLACK HOLE IS PURE NONEXISTENCE?
NO, NO! THE "INTERIOR" OF THE BLACK HOLE IS JUST THE EXTERIOR OF ITS ASSOCIATED WHITE FOUNTAIN.
THE ALERT READER WILL HAVE NOTICED THAT IN THIS MODEL THE BLACK HOLE/ WHITE FOUNTAIN PAIR GIVES ALL THE LAYERS OF COSMIC PARK THE STRUCTURE OF A NONORIENTABLE SURFACE, WITH ONLY ONE SIDE. PASSAGE THROUGH THE HOLE SENDS OBJECTS INTO THEIR MIRROR IMAGES. FOR EXAMPLE, R COMES OUT AS Я.
R
Я

AS CLEAR AS MUD


LENNY, DON'T BE HORRIBLE TO TIRESIAS!
DON'T WORRY, TIRESIAS. THE IMPORTANT THING IS TO BE COMFORTABLE IN YOUR OWN SHELL.
MI!

EPILOGUE


LET ME SEE... VOID AND MATTER ARE THE SAME THING... SPACE CAN CLOSE UP ON ITSELF... AND THE ONLY WAY YOU CAN GO IS STRAIGHT!


IF THIS UNIVERSE IS THE BEST OF ALL POSSIBLE WORLDS, I'M GLAD I DON'T LIVE IN ANY OF THE OTHERS.
A

THE
END