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VSEPR Origami

Student Activity Kit

Introduction

Molecules have shape! The structure and shape of a molecule influences its physical properties and affects its chemical behavior as well. In this activity, you will examine the structures of molecules by creating their geometric shapes from paper using origami techniques. VSEPR theory offers a useful model for visualizing the structures of covalent compounds.

Concepts

- Valence electrons
- Covalent bonding
- VSEPR theory

Background

According to the *Valence Shell Electron Pair Repulsion* (VSEPR) theory, the valence electron pairs that surround an atom repel each other due to their like negative charges. In order to minimize this repulsion, the electron pairs are positioned around the atom so that they are as far apart as possible. The resulting symmetrical arrangement of electron pairs around atoms can be used to predict molecular geometry—the three-dimensional structure and shape of a molecule. Two pairs of electrons around an atom should adopt a linear arrangement, three pairs a trigonal planar arrangement, and so on.

The three-dimensional structure of a molecule is affected by the spatial arrangement of *all* the electron pairs—both bonding and nonbonding—around the central atom. However, only the physical arrangement of the *atoms* is used to describe the resulting molecular geometry. This is best illustrated using an example. The Lewis structure of the water molecule is shown as the first example in Figure 1—there are four pairs of valence electrons around the central oxygen atom. Two pairs of electrons are involved in bonding to hydrogen atoms, while the other two electron pairs are unshared pairs. Four pairs of electrons around an atom will adopt a tetrahedral arrangement in space, to be as far apart in space as possible, as depicted in the second example in Figure 1. For this representation, the symbol "||||||······" shows one lone pair of electrons extending behind the plane of the paper. The symbol "▶" shows one lone pair of electrons extending in front of the plane of the paper, while the symbols "——" represent the hydrogen–oxygen bonds positioned in the plane of the paper. As a result, the two hydrogen atoms and the oxygen atom occupy a "bent" (inverted-V) arrangement, as seen in the third example in Figure 1.

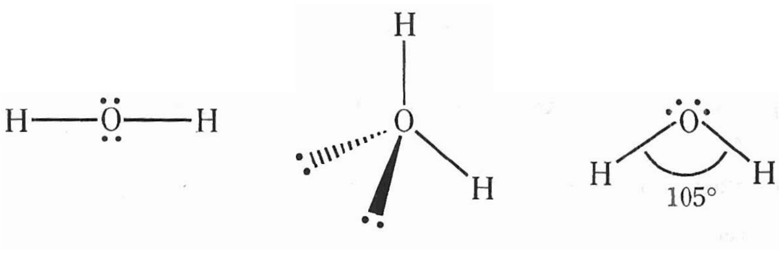


Figure 1. Lewis Structure of Water and Its Molecular Geometry.

When two atoms are linked via a double or triple bond (with two or three bonding pairs of electrons, respectively), the multiple electron pairs between the atoms must be considered together when determining the shape of the molecule. Carbon dioxide provides a good example (Figure 2). The central carbon atom is linked to two oxygen atoms by two double bonds. The resulting arrangement of atoms is linear—both electron pairs in each double bond are considered to be one electron group that must be in approximately the same region, near the oxygen atom.

Figure 2. Lewis Structure of Carbon Dioxide and Its Molecular Geometry.

Experiment Overview

The purpose of this activity is to construct six models of VSEPR molecular geometrics from paper using origami folding techniques.

Pre-Lab Questions *(Use a separate sheet of paper to answer the questions.)*

1. Write the Lewis electron-dot symbol for each of the following atoms: hydrogen, boron, nitrogen, silicon, sulfur, and bromine.
2. What information about a molecule does its Lewis structure provide? What information is neither shown nor implied in the Lewis structure?
3. There are several exceptions to the octet rule.
   - *a.* Based on its electron configuration, explain why hydrogen can only have two valence electrons around it when it bonds to other atoms. What is the maximum number of bonds hydrogen will form?
   - *b.* Neutral compounds of boron may be described as "electron-deficient." Based on its electron configuration, predict how many covalent bonds boron will form. Is this the maximum number of bonds boron will form? *Hint:* Boron forms polyatomic ions.
   - *c.* Many elements in the third row and beyond in the periodic table may form more than four bonds and thus appear to have "expanded octets." Phosphorus and sulfur, for example, may form five and six covalent bonds, respectively. Count up the total number of valence electrons in PCl_5 and draw its Lewis structure. How many valence electrons are "counted" toward the central P atom?

Materials

Molecular geometric forms, 6

Tape, transparent

Scissors

Safety Precautions

Although this activity is considered nonhazardous, observe all normal laboratory safety guidelines.

Procedure

Part A. MX_3 Geometry—Trigonal Pyramidal

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Fold dark, excess flaps between faces labeled 1 and labeled 3 together and tape the flap to the back of face 3. Make sure sides 1, 2, and 3 face each other.
4. Fold dark, excess flaps between faces labeled 1 and 2 together and tape the flap to the back of face 2. Make sure sides 1, 2, and 3 face away from each other.
5. Fold sides labeled 1 together. Tape the edges of sides labeled 2 and the sides labeled 3.

Part B. MX_4 Geometry—Tetrahedral

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Fold the dark excess flaps between faces 2 and 5 together and tape the flap to the back of side 5. Make sure sides 2, 5, and 6 face each other.
4. Repeat step 3 for each of the three remaining dark flaps.

5. Fold faces 1 together, then fold faces 2 together. Tape edges of sides 5 together.
6. Fold faces 3 together. Tape edges of sides 6 together, then tape edges of sides 4 together.

Part C. MX_4 Geometry—Seesaw

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Spread the form out flat.
4. Pick up the form and fold faces labeled 1 together.
5. Fold the dark areas between faces 3 and 4 together.
6. Place the excess fold flush with the back of face 3 and tape the flap in place. Sides 1, 3, and 4 should face each other (see Figure 3).

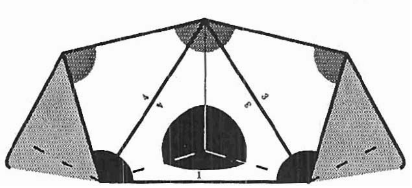


Figure 3.

7. Rotate the form around face 1 and repeat steps 5 and 6 for faces 5 and 2, placing the excess fold flush with the back of face 5. Sides 1, 2, and 5 should face each other.
8. Fold faces 2 together, then fold faces 3 together, making sure the dark excess area is folded in (see Figure 4).

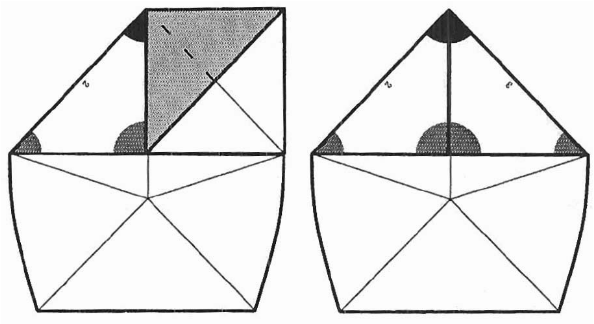


Figure 4.

9. Repeat step 8 for faces 4 and 5.
10. Tape faces 4 and 3 together, then faces 5 and 2.

Part D. MX_5 Geometry—Square Pyramidal

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Fold the dark, excess flaps between faces 6 and 1 together, then bend the flap flush against the back of face 6 and tape. Sides 7, 6, and 1 should face each other (see Figure 5).
4. Repeat step 3 for the other 3 outside squares.
5. Place faces 2 together, then faces 3 together, then faces 4, and faces 1. Tape faces 5 edges together, then face 7 edges, then 6 edges, then 8 edges.

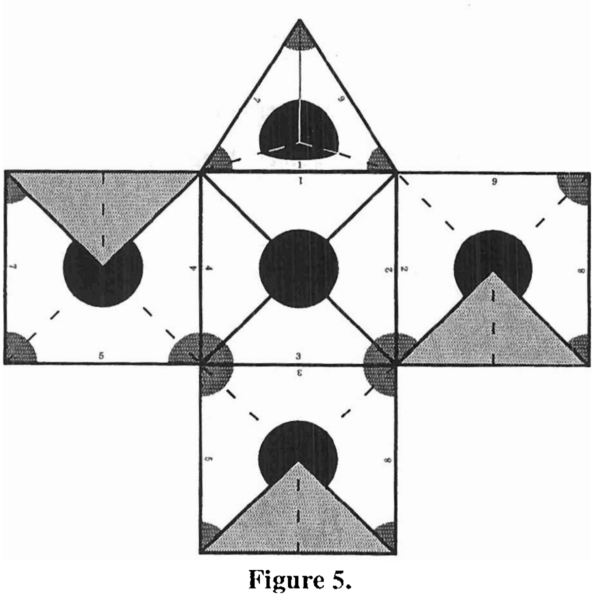


Figure 5.

Part E. MX_5 Geometry—Trigonal Bipyramidal

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Fold the excess flaps between faces 6 and 8 together, then bend the flaps flush against the back of face 8 and tape. Sides 8, 6, and 2 should face each other (see Figure 6).
4. Repeat step 3 for the other three corners.
5. Fold the excess flaps between faces 5 and 2 together, then bend the flaps flush against the back of face 5 and tape. Sides 3, 5, and 2 should face each other.
6. Repeat step 5 for faces, 1, 3, and 4.
7. Fold faces 8 together, then tape the edges together.
8. Fold faces 9 together, then tape the edges together.
9. Tape edges of 7 together, then edges 6.

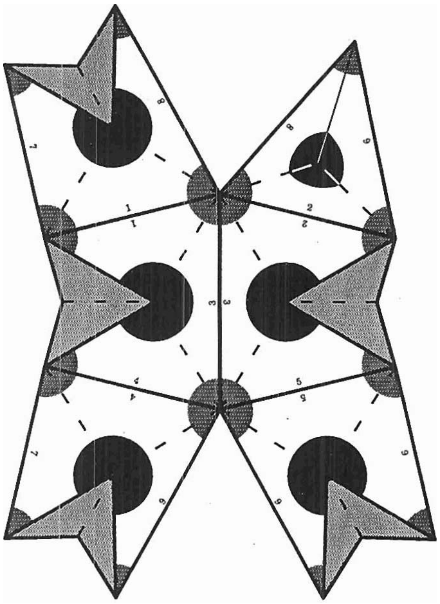


Figure 6.

Part F. MX_4 Geometry—Octahedral

1. Cut out form.
2, Make all folds. For dotted lines, - - -, fold faces together; for solid lines, ——, fold faces apart.
3. Fold faces 1 together.
4. Close the dark excess flaps between faces 6 and 4 together and the excess flaps between 3 and 5. Fold the flaps over and secure with tape to the back of faces 4 and 5, respectively.
5. Repeat steps 3 and 4 for faces labeled 2.
6. On the end with two faces labeled 9, fold the dark area along the dotted line so that sides 7, 12, and 9 face each other and sides 8, 9, and 10 also face each other (see Figure 7).
7. Repeat step 6 for the other end with two faces labeled 11.
8. Fold faces 7 and faces 8 together, then tape faces 9 together along the outside.
9. Fold faces 6 and faces 5 together, then tape faces 11 together along the outside edge.
10. Tape faces 10 together along edge.
11. Tape faces 12 together along edge.

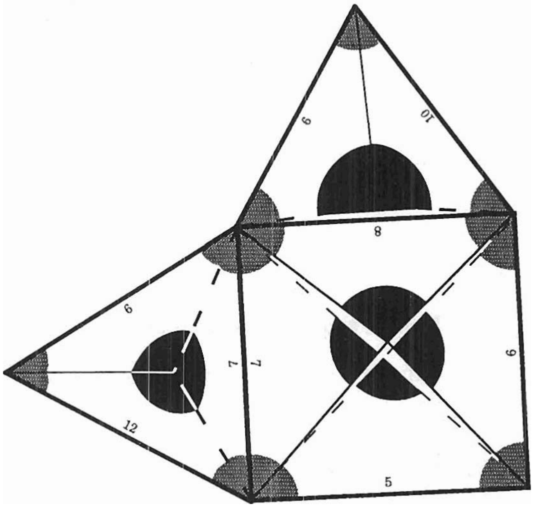


Figure 7.

Name: ______________________________

VSEPR Origami Worksheet

Post-Lab Questions

1. Draw the Lewis structures for each of the following.
   a. BF_3

   b. NH_3

   c. SO_3

   Which molecule(s) has the pyramidal geometry?

2. Draw the Lewis structures for each of the following.
   a. XeF_4

   b. SF_4

   c. CH_4

   Which molecule(s) has the tetrahedral geometry?

3. Draw the Lewis structures for each of the following.
   a. NH_4^+

   b. SF_4

   c. CCl_4

   Which molecule(s) has the seesaw geometry?

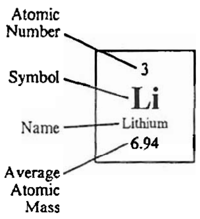
4. Draw the Lewis structures for each of the following.
   a. PF_5

   b. ClF_5

   What is the molecular geometry for each of these molecules?

Periodic Table of the Elements

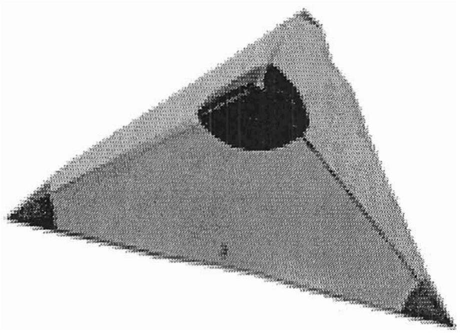
1	1 **H** Hydrogen 1.008																	2 **He** Helium 4.003
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	3 **Li** Lithium 6.94	4 **Be** Beryllium 9.01											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18
3	11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.07	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95
4	19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.88	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80
5	37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium 98.91	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.87	48 **Cd** Cadmium 112.41	49 **In** Indium 114.82	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.75	52 **Te** Tellurium 127.6	53 **I** Iodine 126.90	54 **Xe** Xenon 131.29
6	55 **Cs** Cesium 132.91	56 **Ba** Barium 137.33	57-71 **La-Lu** ★	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.21	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.97	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98	84 **Po** Polonium 208.98	85 **At** Astatine 209.99	86 **Rn** Radon 222.02
7	87 **Fr** Francium 223.02	88 **Ra** Radium 226.03	89-103 **Ac-Lr** #	104 **Rf** Rutherfordium 261.11	105 **Db** Dubnium 262.11	106 **Sg** Seaborgium 263.12	107 **Bh** Bohrium 262.12	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 **Uun** Ununnilium (269)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (277)		114 **Uuq** Ununquadium (289)		116 **Uuh** Ununhexium (289)		



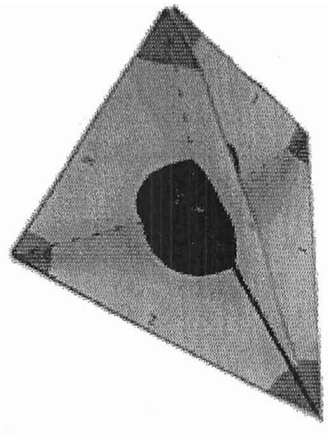
★	57 **La** Lanthanum 138.91	58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium 146.92	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97
#	89 **Ac** Actinium 227.03	90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium 237.05	94 **Pu** Plutonium 244.06	95 **Am** Americium 243.06	96 **Cm** Curium 247.07	97 **Bk** Berkelium 247.07	98 **Cf** Californium 251.08	99 **Es** Einsteinium 252.08	100 **Fm** Fermium 257.10	101 **Md** Mendelevium 258.10	102 **No** Nobelium 259.10	103 **Lr** Lawrencium 260.10

Supplemental Information

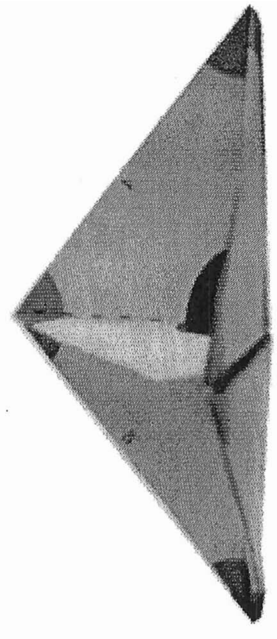
Completed Geometries



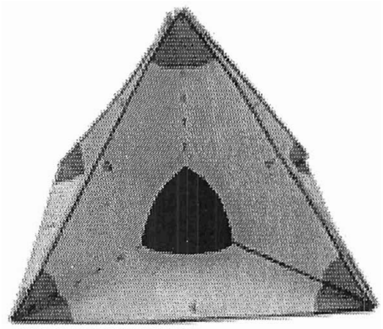
Trigonal Pyramidal



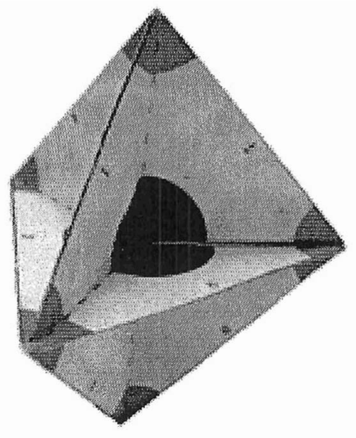
Tetrahedral



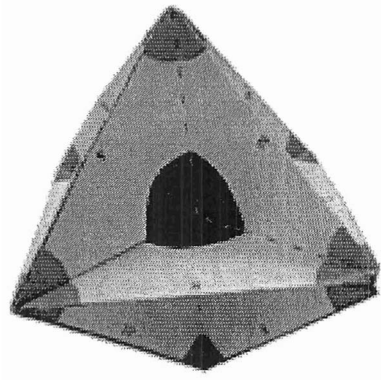
Seesaw



Square Pyramidal

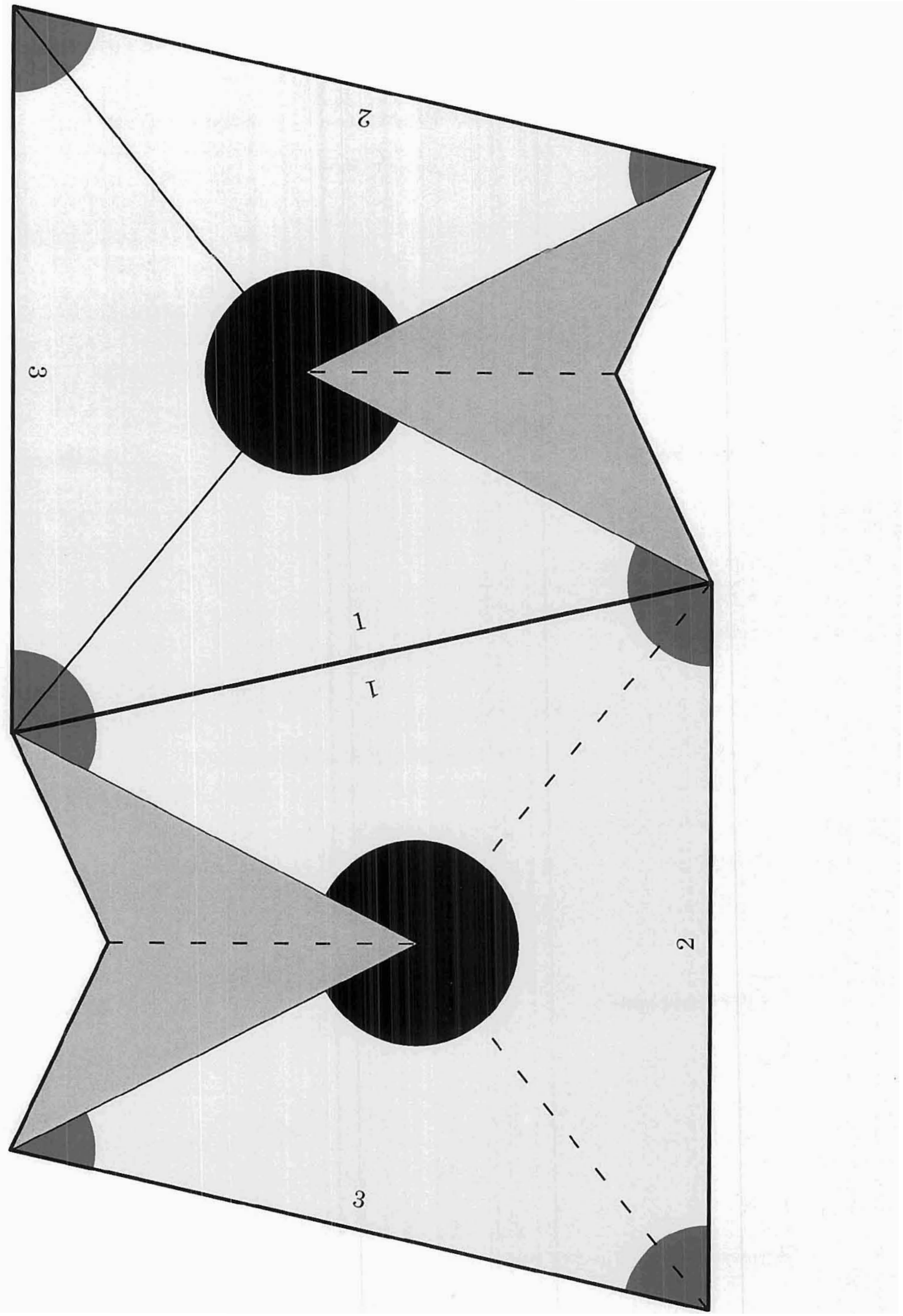


Trigonal Bipyramidal

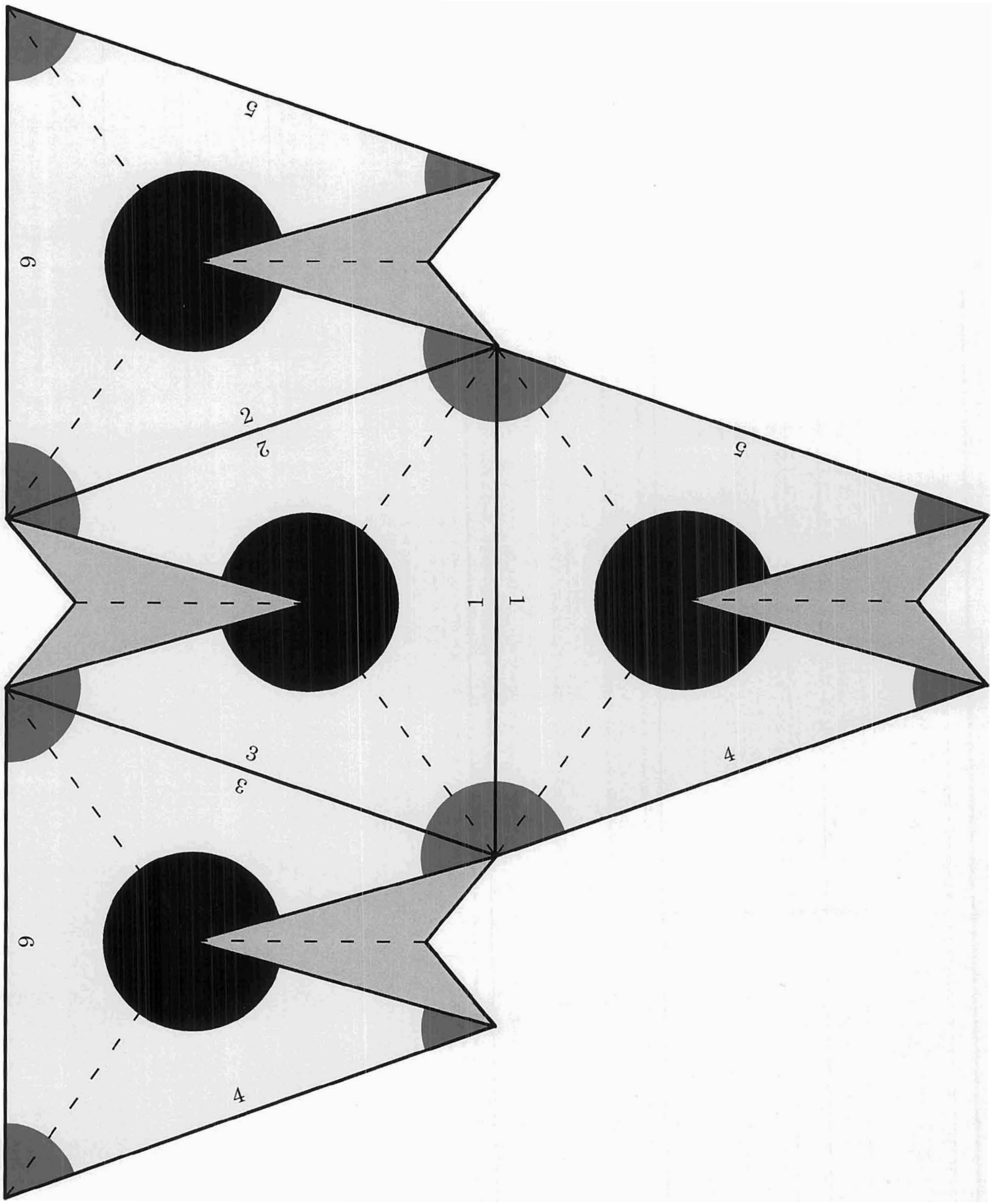


Octahedral

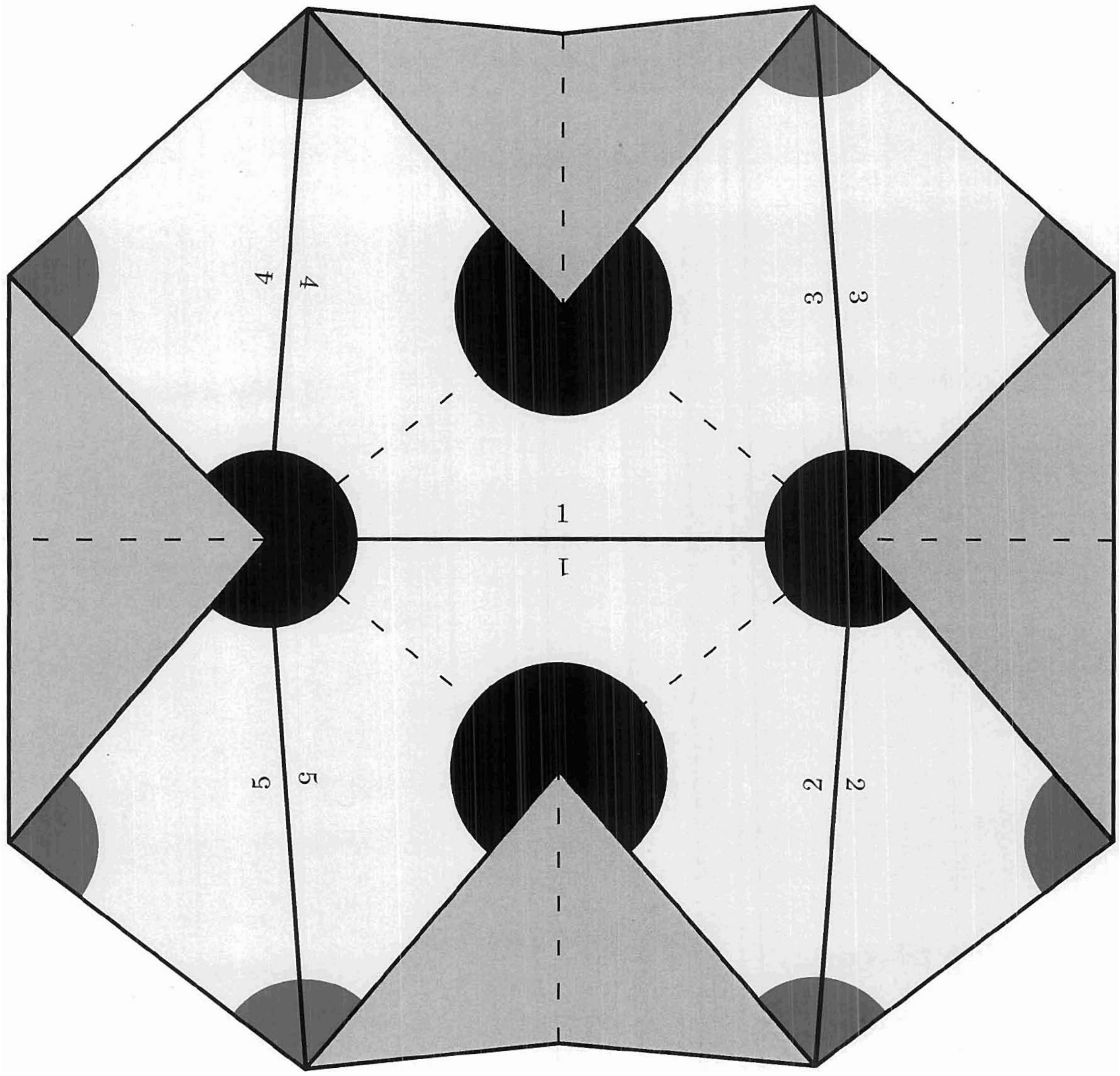
Trigonal Pyramidal



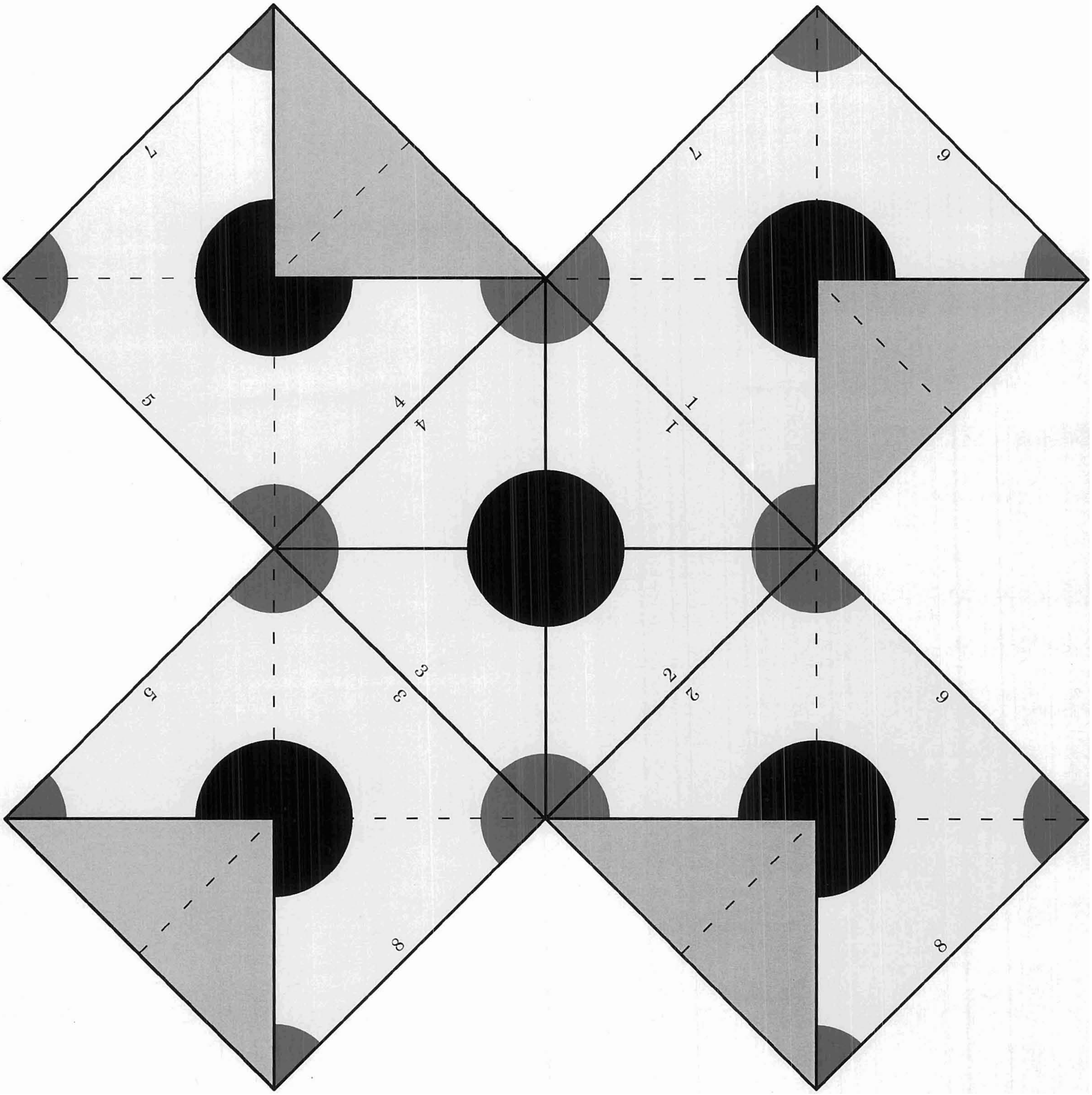
Tetrahedral



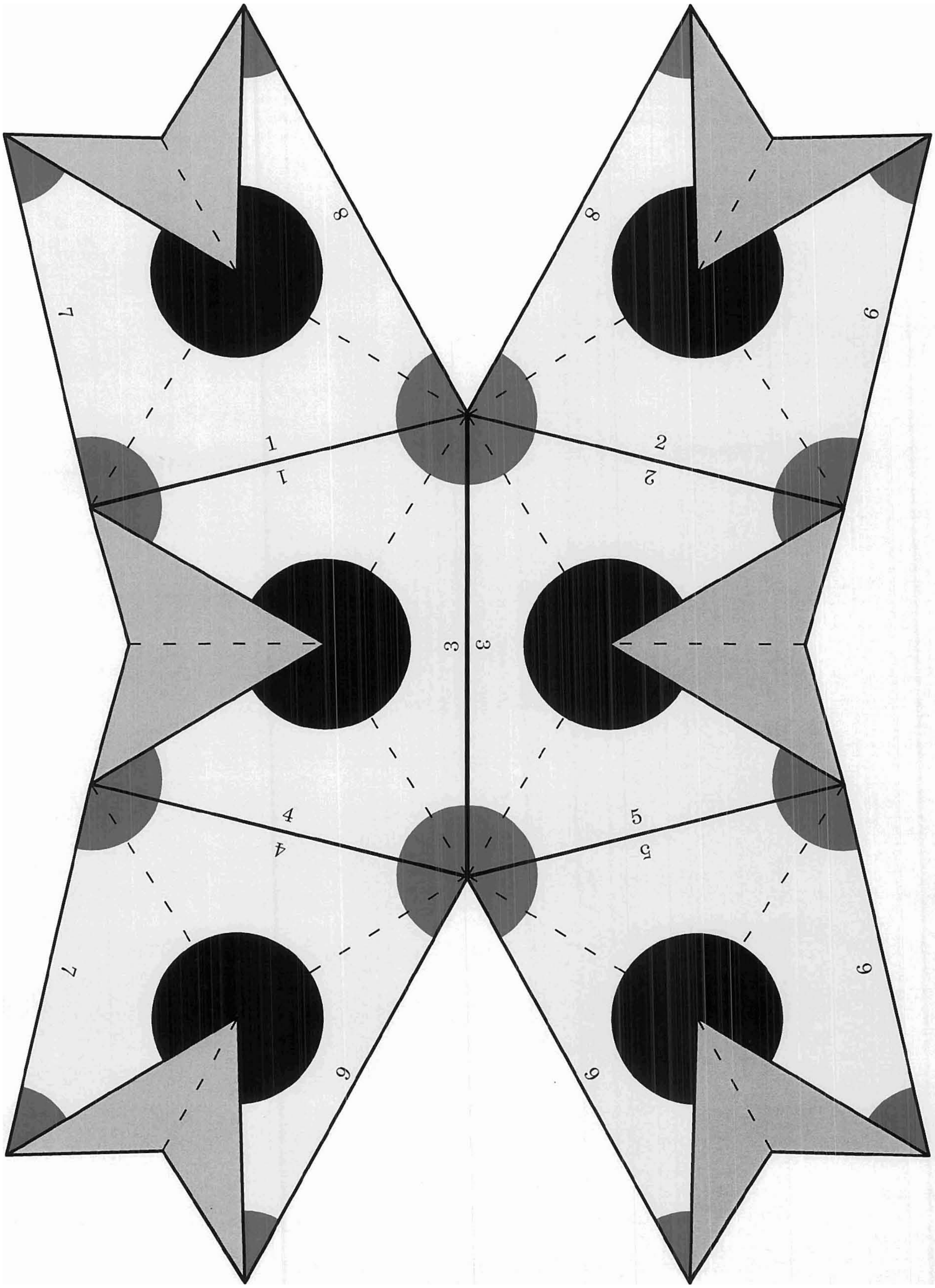
Seesaw



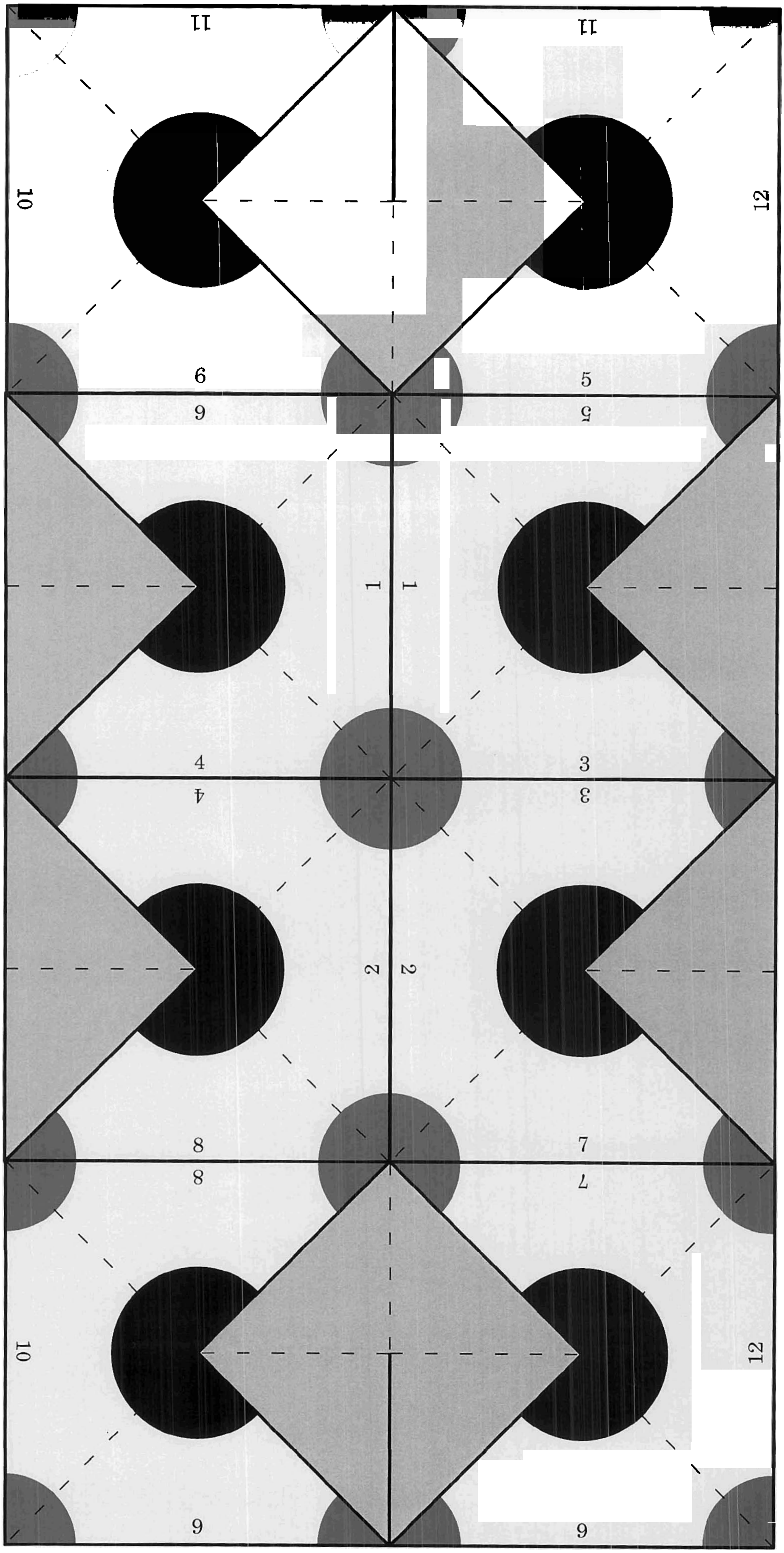
Square Pyramidal



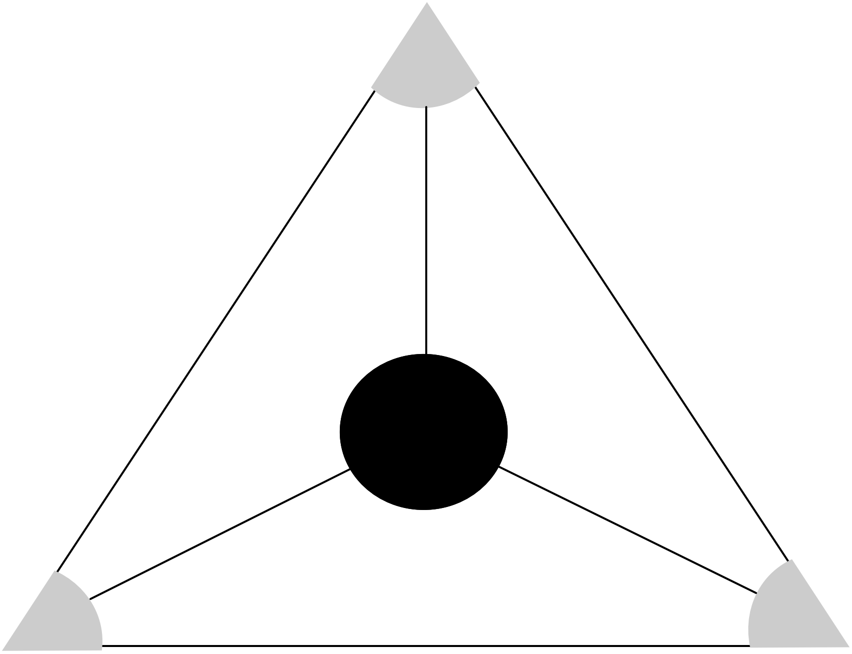
Trigonal Bipyramidal



Octahedral



Trigonal Planar



Linear