1. A circle with radius 1 is circumscribed by a rhombus. What is the minimum possible area of this rhombus?

**Answer:** 4

**Solution:** Work with coordinate axes. Define the unit circle to be $x^2 + y^2 = 1$. An arbitrary rhombus circumscribing a circle with radius 1 will be tangent at four total points, two at $x_0 > 0$ and two at $-x_0$. Then $A = 2 \csc \theta \sec \theta = 4 \frac{1}{2 \sin \theta} \leq 4$, so the minimum value of $A$ is 4.

2. Let $\triangle ABC$ be a right triangle with $\angle ABC = 90^\circ$. Let the circle with diameter $BC$ intersect $AC$ at $D$. Let the tangent to this circle at $D$ intersect $AB$ at $E$. What is the value of $\frac{AE}{BE}$?

**Answer:** 1

**Solution:** Let $O$ be the center of the circle with diameter $BC$. Then $OC = OD$, so $\triangle COD$ is isosceles with $\angle OCD = \angle ODC$. Since $OB \perp AB$, $AB$ is tangent to the circle so $\angle EBD = \angle ODC$. Also, $ED$ is a tangent so $\angle EDO = 90^\circ$. But $\angle EBO = 90^\circ$, so $EDOB$ is cyclic. It follows that $\angle EOD = \angle EBD = \angle ODC = \angle ODC$. This implies that $OE \parallel AC$. Since $O$ is the midpoint of $BC$, $E$ must be the midpoint of $AB$. Therefore, $\frac{AE}{BE} = 1$.

3. Square $ABCD$ has side length 4. Points $P$ and $Q$ are located on sides $BC$ and $CD$, respectively, such that $BP = DQ = 1$. Let $AQ$ intersect $DP$ at point $X$. Compute the area of triangle $PQX$.

**Answer:** $\frac{45}{38}$

**Solution:** Notice that the desired area is $[PQD] - [QDX]$. By the standard area of a triangle formula, $[PQD] = \frac{1}{2} \cdot 1 \cdot 3 = \frac{3}{2}$. Let $\angle QDX = \angle CDP = \theta$. Since triangle $PCD$ is a $3-4-5$ right triangle, we have $\sin \theta = \frac{3}{5}$ and $\cos \theta = \frac{4}{5}$. Now by the sine area formula, $[QDA] = 2 - [QDX] + [XDA] = \frac{1}{2} \cdot DX \cdot (\sin \theta + 4 \cos \theta)$, so solving for $DX$ gives $DX = \frac{20}{19}$. Thus $[QDX] = \frac{1}{2} \cdot 1 \cdot \frac{20}{19} \cdot \frac{3}{5} = \frac{6}{19}$. Our answer is $\frac{3}{2} - \frac{6}{19} = \frac{45}{38}$.

4. Let $ABCD$ be a quadrilateral such that $AB = BC = 13$, $CD = DA = 15$ and $AC = 24$. Let the midpoint of $AC$ be $E$. What is the area of the quadrilateral formed by connecting the incenters of $ABE$, $BCE$, $CDE$, and $DAE$?

**Answer:** 25

**Solution:** Since $E$ is the midpoint of $AC$, $AE = CE = 12$. Also, from $AB = BC$ and $CD = DA$, we see that $ABCD$ is a kite and $AC \perp BD$. By the Pythagorean Theorem on the four right triangles, we find that $AE = 5$ and $DE = 9$.

Let $W$, $X$, $Y$, and $Z$ be the incenters of $\triangle ABE$, $\triangle BCE$, $\triangle CDE$ and $\triangle DAE$ respectively. Note that $WX \parallel AC$ and $YZ \parallel AC$ and by symmetry, $WZ = XY$, so $WXYZ$ is an isosceles trapezoid. The semiperimeter of $\triangle ABE$ is $\frac{5 + 12 + 13}{2} = 15$, so the inradius is $15 - 13 = 2$. Similarly, we can compute that the inradius of $\triangle CDE$ is $\frac{9 + 12 + 15}{2} - 15 = 3$. It follows that $WX = 2(2) = 4$ and $YZ = 2(3) = 6$. Drawing perpendiculars from $W$ to $AC$ and $Z$ to $AC$, we see that these perpendiculars are exactly the inradii of $\triangle ABE$ and $\triangle DAE$ respectively, so the height of the trapezoid is $2 + 3 = 5$. Thus, the area of $WXYZ$ is $\frac{10(5)}{2} = 25$.

5. Find the smallest possible number of edges in a convex polyhedron that has an odd number of edges in total has an even number of edges on each face.

**Answer:** 19
**Solution:** Because each edge is part of two distinct faces, we can think of a face with $2k$ edges as contributing $k$ edges to the total edge count of the polyhedron. Then in order for the total edge count to be odd, we see that there must be an odd number of faces that have $2 \pmod{4}$ edges.

Since our goal is to minimize the number of edges, note that the smallest possible $2 \pmod{4}$ face is a hexagon. Let us attempt to construct an example starting with a single hexagon as the only $2 \pmod{4}$ face. This necessitates having at least six other faces – one for each edge of the hexagon. Since all must be $0 \pmod{4}$ faces, our best bet is to make them all quadrilaterals. In order to minimize the number of loose edges, we make every two quadrilaterals that are adjacent along the hexagon share an edge. We now have six loose edges left to cover. Note that we can do this with two more quadrilaterals. The resulting polyhedron has 19 edges in total, with one hexagonal face and eight quadrilateral faces:

We now claim this is the minimum possible number of edges for such a polyhedron. Indeed, the construction argument already explains why it is the optimal solution with exactly one hexagon and no other $2 \pmod{4}$ faces. Furthermore, notice that the presence of an octagon or a decagon necessitates at least 8 other faces and thus at least 16 other edges, which already surpasses the 19 edges in our example. So we restrict our search to polyhedrons of hexagons and quadrilaterals. In particular, the only case we have left to rule out is three or more hexagons – but introducing three hexagons already forces at least 15 edges. One can quickly convince oneself that strictly more than 4 additional edges are needed to close a polyhedron. (To rigorize this, we can consider three cases: if there exists a hexagon not adjacent to the other hexagons, if the three hexagons are pairwise adjacent but don’t share a vertex, or if all three hexagons share a vertex.) We conclude that the answer is 19.

6. Consider triangle $ABC$ on the coordinate plane with $A = (2, 3)$ and $C = (\frac{96}{13}, \frac{207}{13})$. Let $B$ be the point with the smallest possible $y$-coordinate such that $AB = 13$ and $BC = 15$. Compute the coordinates of the incenter of triangle $ABC$.

**Answer:** (8, 7)

**Solution:** First, note that

$$AC = \sqrt{\left(\frac{96}{13} - 2\right)^2 + \left(\frac{207}{13} - 3\right)^2} = \sqrt{\left(\frac{70}{13}\right)^2 + \left(\frac{168}{13}\right)^2} = \sqrt{\left(\frac{14}{13}\right)^2 (5^2 + 12^2)} = 14$$

so $ABC$ is a 13-14-15 triangle. Using Heron’s Formula, we have that the area of $ABC$ is 84. Then, if $r$ is the inradius, $\frac{13 + 14 + 15}{2} \cdot r = 84 \implies r = 4$. Furthermore, we can draw a
perpendicular from $B$ to $AC$ to split the 13-14-15 triangle into a 5-12-13 triangle and a 9-12-15
triangle. It follows that $\tan BAC = \frac{12}{5}$. But the slope of line $AC$ is
\[ \frac{168}{13} = \frac{168}{70} = \frac{12}{5} \]
so in fact side $AB$ is parallel to the $x$-axis.

Let $I$ be the incenter and let $X$ be the point of tangency of the incircle to $AB$. We have that
$AX = \frac{13+14+15}{2} - 15 = 6$, so $X = (8, 3)$. But $IX \perp AB$ and $IX = 4$, so $X = (8, 7)$.

7. Let $ABC$ be an acute triangle with $BC = 4$ and $AC = 5$. Let $D$ be the midpoint of $BC$, $E$ be
the foot of the altitude from $B$ to $AC$, and $F$ be the intersection of the angle bisector of $\angle BCA$
with segment $AB$. Given that $AD$, $BE$, and $CF$ meet at a single point $P$, compute the area of
triangle $ABC$. Express your answer as a common fraction in simplest radical form.

**Answer:** $20 \sqrt{14}/9$

**Solution:** By the Angle Bisector Theorem, $\frac{BE}{AF} = \frac{4}{5}$. Then by Ceva’s theorem we see that
$\frac{CE}{AE} = \frac{9}{8}$, so $CE = \frac{20}{9}$ and $AE = \frac{25}{9}$. By the Pythagorean theorem, $BE = \frac{8\sqrt{14}}{9}$, so the area of
$\triangle ABC$ is $\frac{1}{2} \cdot 5 \cdot \frac{8\sqrt{14}}{9} = \frac{20\sqrt{14}}{9}$.

8. Consider an acute angled triangle $\triangle ABC$ with side lengths 7, 8, and 9. Let $H$ be the orthocenter
of $ABC$. Let $\Gamma_A$, $\Gamma_B$, and $\Gamma_C$ be the circumcircles of $\triangle BCH$, $\triangle CAH$, and $\triangle ABH$ respectively.
Find the area of the region $\Gamma_A \cup \Gamma_B \cup \Gamma_C$ (the set of all points contained in at least one of $\Gamma_A$, $\Gamma_B$, and $\Gamma_C$).

**Answer:** $\frac{441\pi}{10} + 24\sqrt{5}$

**Solution:** Let $H_A$ be the reflection of $H$ across side $BC$. Note that $\angle AH_A B = \angle BHH_A = 90^\circ - \angle HBC = \angle ACB$, so $H_A$ lies on $\Gamma$, the circumcircle of $\triangle ABC$. In other words, the circumcircle of $BHH_A$ is precisely $\Gamma$. So $\Gamma_A$ – the circumcircle of $BHC$ – is the reflection of $\Gamma$ across side $BC$. Similarly, $\Gamma_B$ and $\Gamma_C$ are the reflections of $\Gamma$ across sides $CA$ and $AB$.

Let $O_A$, $O_B$, and $O_C$ be the centers of $\Gamma_A$, $\Gamma_B$, and $\Gamma_C$. We can write the area of $\Gamma_A \cup \Gamma_B \cup \Gamma_C$ as
the area of hexagon $AO_CBO_ACO_B$ plus the three external circular sectors $AO_CB$, $BO_A$, and
$CO_AB$. Notice that $\angle AOC + \angle BOC + \angle COA = 360^\circ$, so the sum of the areas of these three sectors is precisely twice the area of $\Gamma$. Furthermore, note that $\lbrack AO_CBO_ACO_B \rbrack = \lbrack AO_CB \rbrack + \lbrack BO_A \rbrack + \lbrack CO_AB \rbrack + \lbrack ABC \rbrack = \lbrack AOB \rbrack + \lbrack BOC \rbrack + \lbrack COA \rbrack + \lbrack ABC \rbrack = 2 \lbrack ABC \rbrack$.

We can compute $\lbrack ABC \rbrack = 12\sqrt{5}$ by Heron’s, and then the circumradius $R$ is $\frac{\sqrt{5}}{\lbrack ABC \rbrack} = \frac{21\sqrt{5}}{10}$. Thus the area of $\Gamma$ is $\pi R^2 = \frac{441\pi}{20}$. So our final answer is $2\pi R^2 + 2 \lbrack ABC \rbrack = \frac{441\pi}{10} + 24\sqrt{5}$.

9. Let $ABC$ be a right triangle with hypotenuse $AC$. Let $G$ be the centroid of this triangle and
suppose that we have $AG^2 + BG^2 + CG^2 = 156$. Find $AC^2$.

**Answer:** 234

**Solution:** Let $AB = x$ and $BC = y$. Let $D$, $E$, $F$ be the midpoints of $BC$, $AC$, $AB$ respectively.
Since $G$ is a centroid, we have $AG = 2GD$, $BG = 2GE$, $CG = 2GF$. Also, since $ABC$ is a right
triangle and $E$ is the midpoint of $AC$, we must have $BE = EA = EC = \frac{1}{2}AC$. Hence,

$$AG^2 + BG^2 + CG^2 = \left( \frac{2}{3}AD \right)^2 + \left( \frac{2}{3}BE \right)^2 + \left( \frac{2}{3}CF \right)^2$$

$$= \frac{4}{9} \left( x^2 + \left( \frac{y}{2} \right)^2 + \frac{x^2 + y^2}{4} + y^2 + \left( \frac{x}{2} \right)^2 \right)$$

$$= \frac{4}{9} \left( \frac{3x^2 + 3y^2}{2} \right)$$

$$= \frac{2}{3} (x^2 + y^2)$$

$$= 156.$$ 

Therefore, $AC^2 = x^2 + y^2 = \frac{3}{2} \cdot 156 = 234.$

10. Three circles with radii 23, 46, and 69 are tangent to each other as shown in the figure below (figure is not drawn to scale).

Find the radius of the largest circle that can fit inside the shaded region.

**Answer:** 6

**Solution:** Let $A, B, C$ be the center of the three circles with radii $a = 23, b = 46, c = 69$ respectively and let $O$ and $r$ be the center and the radius of the largest circle that can fit in the shaded region. Hence, we have a triangle $ABC$ with sides 69, 92, and 115 and a point $O$ inside the triangle with distances $23 + r$, $46 + r$, and $69 + r$ from $A, B, C$ respectively.

Suppose $CO$ intersects $AB$ at $X$ and let $OX = x$ and $AX = y.$
Then, by Stewart’s Theorem, we have

\[ AO^2 XC = AC^2 OX + AX^2 OC - (OX)(OC)(XC), \]
\[ BO^2 XC = BC^2 OX + BX^2 OC - (OX)(OC)(XC), \]
\[ OX^2 AB = OA^2 XB + OB^2XA - (XB)(XA)(BA). \]

Substituing in the values,

\[ (23 + r)^2(69 + r + x) = 92^2x + y^2(69 + r) - x(69 + r)(69 + r + x), \]
\[ (46 + r)^2(69 + r + x) = 115^2 x + (69 - y)^2(69 + r) - x(69 + r)(69 + r + x), \]
\[ x^2(69) = (23 + r)^2(69 - y) + (46 + r)^2(y) - (69 - y)(y)(69). \]

Solving these equations such that \( r > 0 \) yields \( x = \frac{125}{6}, y = \frac{161}{6}, r = 6 \).