# 9.9 Finding the Area of the Region Bounded by Two Polar Curves

Name: _____ Class: _____ Date: _____ **Total: 36 marks**

**KEY WORDS** meeting point • inside • outside • cardioid • pole • region

## Objective

Build the skills to answer exam questions on **the area between two polar curves** : finding where the curves meet, $\frac{1}{2}\int(R^2-r^2)\,d\theta$, and regions inside one curve and outside another.

**You must be able to:**

- find the angles where two polar curves meet by solving $f(\theta)=g(\theta)$
- write the area inside $R=f(\theta)$ and outside $r=g(\theta)$ as $\frac{1}{2}\int(R^2-r^2)\,d\theta$
- evaluate such integrals with the double-angle identities
- build an area from simpler areas by adding or subtracting

## 1 Key knowledge and worked examples

### ■ Area between polar curves

| idea | rule |
|---|---|
| meeting points | solve $f(\theta)=g(\theta)$; also check the pole, where $r=0$ on each curve |
| inside $R$, outside $r$ | $A=\dfrac{1}{2}\displaystyle\int_{\alpha}^{\beta}\left(R^2-r^2\right)d\theta$, where $R\geq r$ on $[\alpha,\beta]$ |
| not | $\frac{1}{2}\int(R-r)^2\,d\theta$ |
| limits | the angles of the meeting points that bound the region |
| build up | inside both = one whole area − the part outside the other |
| identities | $\sin^2\theta=\frac{1}{2}(1-\cos 2\theta)$, $\cos^2\theta=\frac{1}{2}(1+\cos 2\theta)$ |



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**Worked example 1: inside a circle, outside another.** Inside $r = 2\sin\theta$ and outside $r = 1$.

1. Known: $2\sin\theta = 1$ at $\theta = \frac{\pi}{6}$ and $\frac{5\pi}{6}$.
2. Rule: $\dfrac{1}{2}\displaystyle\int_{\pi/6}^{5\pi/6} (4\sin^2\theta - 1)\,d\theta = \frac{1}{2}\int_{\pi/6}^{5\pi/6} (1 - 2\cos 2\theta)\,d\theta.$
3. Numbers: $\dfrac{1}{2}\Big[\theta - \sin 2\theta\Big]_{\pi/6}^{5\pi/6} = \dfrac{1}{2}\left(\dfrac{2\pi}{3} + \sqrt{3}\right).$
4. Result: $\dfrac{\pi}{3} + \dfrac{\sqrt{3}}{2}$.

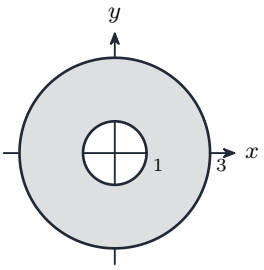
**Worked example 2: meeting points.** Where do $r = 1$ and $r = 2\cos\theta$ meet, $-\frac{\pi}{2} \le \theta \le \frac{\pi}{2}$?

1. Known: $2\cos\theta = 1$.
2. Rule: $\cos\theta = \frac{1}{2}$.
3. Numbers: $\theta = \pm\frac{\pi}{3}$, with $r = 1$.
4. Result: $\left(\frac{1}{2}, \pm\frac{\sqrt{3}}{2}\right)$ in Cartesian form.

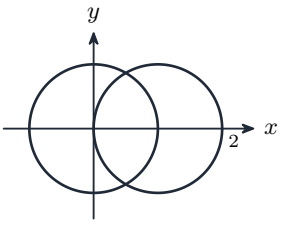
**Answer shapes:** sketch or read the figure to decide which curve is outside; write the limits next to the integral.

## 2 Practice

**2.1** Find the area of the ring between the circles $r = 3$ and $r = 1$. [2]



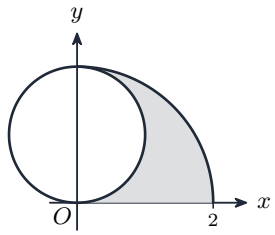

**2.2** Find the points where the circles $r = 1$ and $r = 2\cos\theta$ meet. Give them in polar and in Cartesian form. [3]





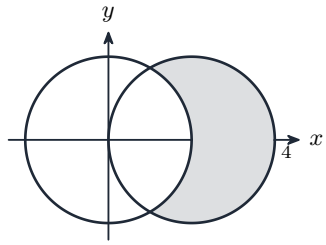

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**2.3** Find the area of the region inside $r = 2$ and outside $r = 2\sin\theta$, for $0 \leq \theta \leq \frac{\pi}{2}$. [3]




## 3 Exam-style questions

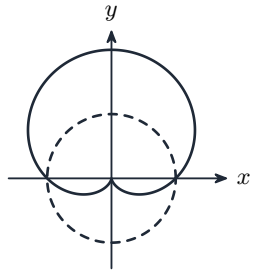
**3.1** Find the exact area of the region inside $r = 4\cos\theta$ and outside $r = 2$. [4]




**3.2** The cardioid $r = 1 + \sin\theta$ and the circle $r = 1$ are shown.

(a) Find the values of $\theta$ in $[0, 2\pi)$ where the curves meet. [2]

(b) Find the area inside the cardioid and outside the circle. [3]




(c) Find the area inside the circle and outside the cardioid. [1]

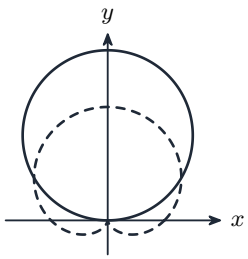


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**3.3** The circle $r = 3\sin\theta$ and the cardioid $r = 1 + \sin\theta$ are shown. They meet at two points and at the pole.

(a) Find the Cartesian coordinates of the two points where the curves meet, other than the pole. [3]

(b) Find the area of the region inside the circle and outside the cardioid. [4]






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(c) Find the area of the region inside both curves. Give the exact value and a decimal. [5]

(d) Find the area of the region inside the cardioid and outside the circle. [6]



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