

$$22. \mathbf{r}(u, v) = \sin u \sin v \mathbf{i} + \cos u \sin v \mathbf{j} + \sin v \mathbf{k};$$

$$0 \leq u \leq 2\pi, 0 \leq v \leq 2\pi$$

$$23. \mathbf{r}(u, v) = u^2 \cos v \mathbf{i} + u^2 \sin v \mathbf{j} + 2v \mathbf{k}; 0 \leq u \leq 2\pi,$$

$$0 \leq v \leq 2\pi$$

$$24. \mathbf{r}(u, v) = \cos u \cos v \mathbf{i} + \cos u \sin v \mathbf{j} + \cos v \mathbf{k};$$

$$0 \leq u \leq \pi/2, 0 \leq v \leq 2\pi$$

25. Find the mass of the surface in Problem 23 if the density is proportional to the distance from the xy -plane.

26. Find the mass of the surface in Problem 24 if the density is proportional to (a) the distance from the z -axis, and (b) the distance from the xy -plane.

27. Show that the magnitude of the cross product $[\mathbf{r}_u(u, v) \times \mathbf{r}_v(u, v)]$ in Example 9 is equal to $25 |\sin v|$.

28. Refer to Example 3. The hemispherical surface $z = f(x, y) = \sqrt{9 - x^2 - y^2}$ has a thin metal covering with density $\delta(x, y, z) = z$. Find the mass of this covering. Note that Theorem A does not apply directly, since f_x and f_y are undefined on the boundary $x^2 + y^2 = 9$ of R . Therefore, proceed by letting R_ϵ be the region $0 \leq x^2 + y^2 \leq (3 - \epsilon)^2$, make the calculation, and then let $\epsilon \rightarrow 0$. Discover that you get the same answer as you would if you ignored this subtle point.

29. Let G be the sphere $x^2 + y^2 + z^2 = a^2$. Evaluate each of the following:

$$(a) \iint_G z \, dS$$

$$(b) \iint_G \frac{x + y^2 + \sin z}{1 + z^2} \, dS$$

$$(c) \iint_G (x^2 + y^2 + z^2) \, dS$$

$$(d) \iint_G x^2 \, dS$$

$$(e) \iint_G (x^2 + y^2) \, dS$$

Hint: Use symmetry properties to make this a trivial problem.

30. The sphere $x^2 + y^2 + z^2 = a^2$ has constant area density k . Find each moment of inertia.

(a) About a diameter

(b) About a tangent line (assume the Parallel Axis Theorem from Problem 29 of Section 13.5).

31. Find the total force against the surface of a tank full of a liquid of weight density k for each tank shape.

(a) Sphere of radius a

(b) Hemisphere of radius a with a flat base

(c) Vertical cylinder of radius a and height h

Hint: The force against a small patch of area ΔG is approximately kad , where d is the depth of the water at the patch.

32. Find the center of mass of that part of the sphere $x^2 + y^2 + z^2 = a^2$ between the planes $z = h_1$ and $z = h_2$, where $0 < h_1 < h_2 < a$. Do this by the methods of this section and then compare with Problem 19 of Section 13.6.

Answers to Concepts Review: 1. surface integral

$$2. \sum_{i=1}^n g(x_i, y_i, z_i) \Delta S_i \quad 3. \sqrt{f_x^2 + f_y^2 + 1} \quad 4. 2; 18\pi$$

14.6 Gauss's Divergence Theorem

The Boundary of a Set

Recall from Section 12.3 that a point P is a boundary point for a set S if every neighborhood of P contains points that are in S and points that are not in S . The boundary of a set is the set of all its boundary points.

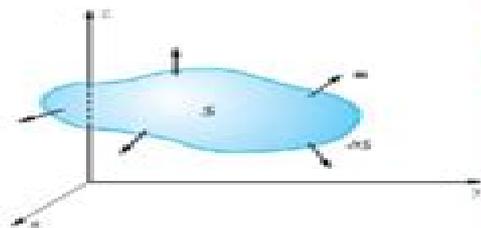


Figure 1

The theorems of Green, Gauss, and Stokes all relate an integral over a set S to another integral over the boundary of S . To emphasize the similarity in these theorems, we introduce the notation ∂S to stand for the boundary of S . Thus, one form of Green's Theorem (Section 14.4) can be written as

$$\oint_{\partial R} \mathbf{F} \cdot \mathbf{n} \, ds = \iint_R \operatorname{div} \mathbf{F} \, dA$$

It says that the flux of \mathbf{F} across the boundary ∂S of a closed bounded plane region S is equal to the double integral of $\operatorname{div} \mathbf{F}$ over that region. Gauss's Theorem (also called the *Divergence Theorem*) lifts this result up one dimension.

Gauss's Theorem Let S be a closed bounded solid in three-space that is completely enclosed by a piecewise smooth surface ∂S (Figure 1).

Theorem A Gauss's Theorem

Let $\mathbf{F} = M\mathbf{i} + N\mathbf{j} + P\mathbf{k}$ be a vector field such that M , N , and P have continuous first-order partial derivatives on a solid S with boundary ∂S . If \mathbf{n} denotes the outer unit normal to ∂S , then

$$\iint_{\partial S} \mathbf{F} \cdot \mathbf{n} \, dS = \iiint_S \operatorname{div} \mathbf{F} \, dV$$

In other words, the flux of \mathbf{F} across the boundary of a closed region in three-space is the triple integral of its divergence over that region.

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