Improving efficiency in instruction: Gauss's law

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Physics Education Group
University of Washington

July 18th, 2016
AAPT Summer Meeting


ACCUWAVE DS

Tutorials in introductory physics

University of Washington

Introductory physics:

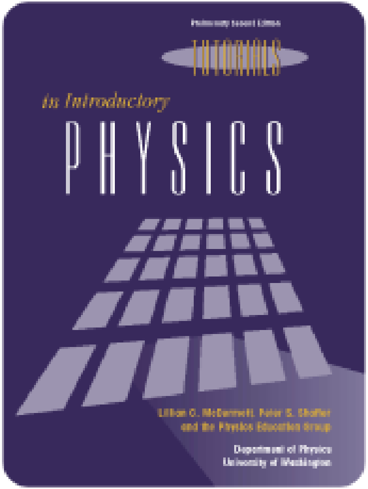
- 3 hrs/week lecture
- 1 hr/week tutorial
- 2 hrs/week lab

Tutorials in introductory physics

University of Washington

Introductory physics

- 1 hr/week tutorial
- Each tutorial addresses known student difficulties



Physics Education Group

Research · Curriculum · Instruction

Research Curriculum Instruction

Physics Education Group

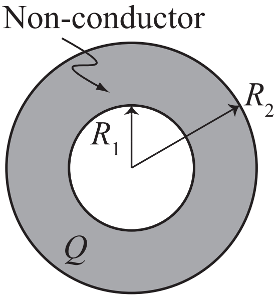
- 10 or fewer weekly tutorials

Topics to combine

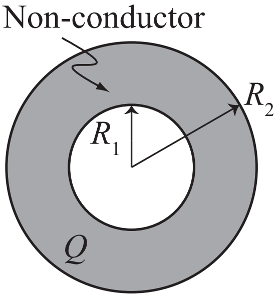
- Forces & Newton's second and third laws
- Lenz's law & Faraday's law
- Electric field and flux & Charge
- Electric field and flux & Gauss's law

Topics to combine

- Forces & Newton's second and third laws
- Lenz's law & Faraday's law
- Electric field and flux & Charge
- **Electric field and flux & Gauss's law**



- Total charge Q spread throughout volume
- Thick spherical shell, insulator
- Question: Find $|\vec{E}|$ in the shell.



- Total charge Q spread throughout volume
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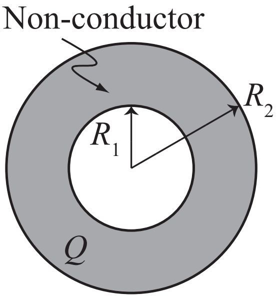
- Question: Find $|\vec{E}|$ in the shell.

Required concepts:

- Distributed charges
- Charge density
- Surface area *vs.* volume
- Electric field
- Electric flux



- Total charge Q spread throughout volume
- Thick spherical shell, insulator
- Question: Find $|\vec{E}|$ in the shell.

$$N = 308$$

15% obtained a correct expression.

$< 5\%$ explained how they obtained correct expressions.

The literature

- The *Gauss's law* tutorial improves conceptual understanding of Gauss's law.[1]

[1]Kanim, S. (1999)

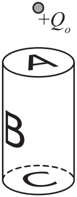
The literature

- The *Gauss's law* tutorial improves conceptual understanding of Gauss's law.[1]
- Helping students learn about symmetry with flux and applicability of Gauss's law improves understanding and problem solving ability.[2]

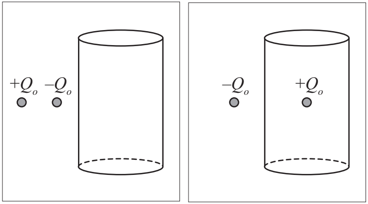
[1] Kanim, S. (1999)
[2] Singh, C. (2006)

Gauss's law tutorial coverage

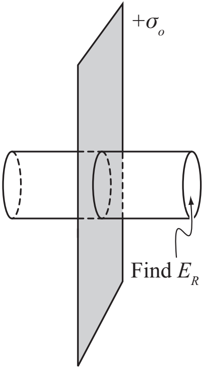
Flux practice



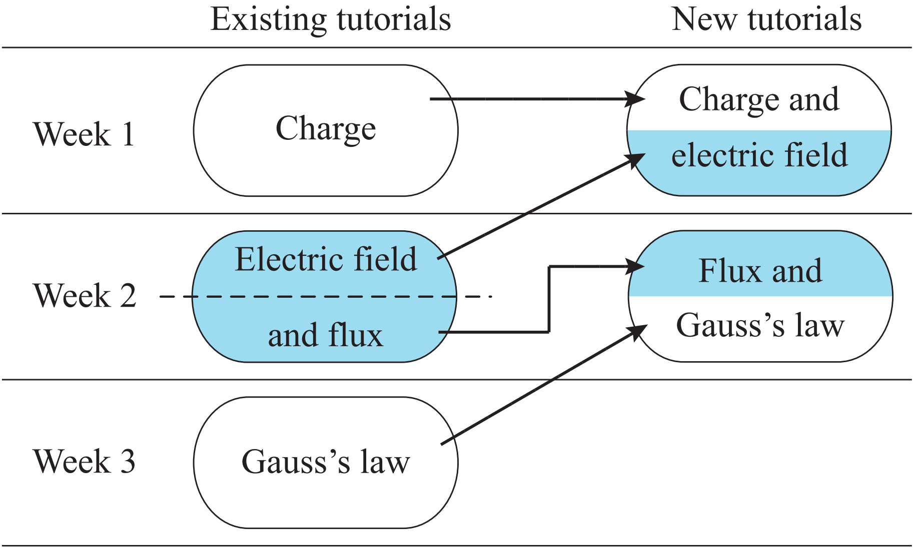
Finding basic Q_{enc}

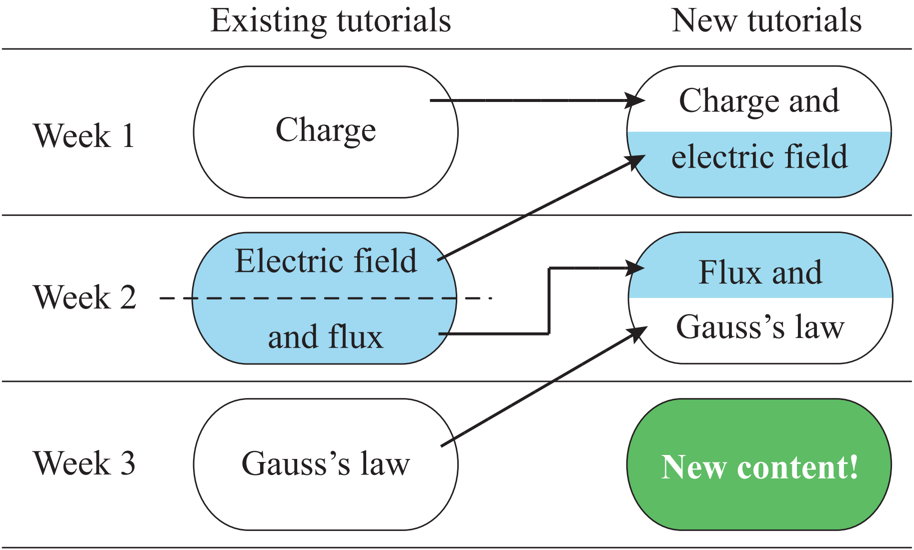


Example calculation



	Existing tutorials
Week 1	Charge
Week 2	Electric field and flux
Week 3	Gauss's law


Existing tutorials
New tutorials
Week 1
Charge
Charge and
electric field
Week 2
Electric field
and flux
Flux and
Gauss's law
Week 3
Gauss's law


Existing tutorials
New tutorials
Week 1
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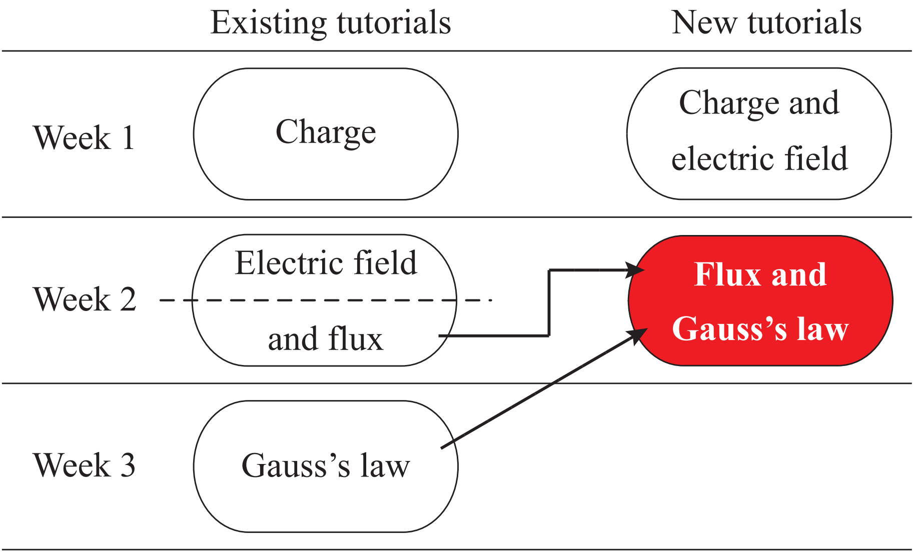
New content!


Existing tutorials
New tutorials
Week 1
Charge
Charge and electric field
Week 2
Electric field and flux
Flux and Gauss's law
Week 3
Gauss's law

Electric field and flux (existing)

- Area vector
- Relate electric force to field
- Explore the field of a vertical charged rod
- Test charge independence
- Finding sign of flux
- Electric field lines

Flux and Gauss's law (new)

- Area vector
- Finding flux signs **and magnitudes**
- Finding flux in a non-uniform field
- **Relate** basic Q_{enc} **to independently found** Φ_{net}
- **Confront difficulties about non-closed surfaces** *(BASED ON SINGH 2006)*
- **Symmetry considerations** *(BASED ON SINGH 2006)*

Gauss's law (existing)

- Finding flux in a non-uniform field
- Verify Gauss's law consistency
- Finding basic Q_{enc}
- Applying Gauss's law
- Superposition in Gauss's law

(To HW)

Research
Curriculum
Instruction

Physics Education Group

Difficult for students:[1]

- Flux through portion of a Gaussian surface
- Superposition and "blocking" of fields
- Tutorial helps with these

[1] Kanim, S. (1999)

Difficult for students:[1]

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- Superposition and "blocking" of fields
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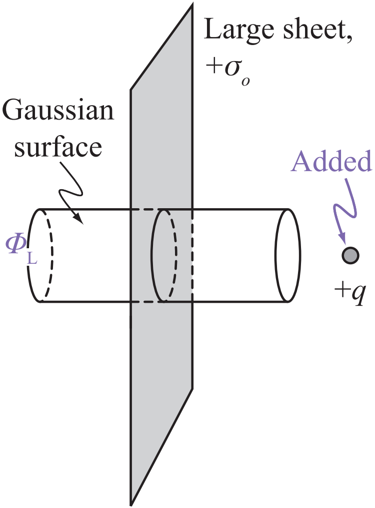
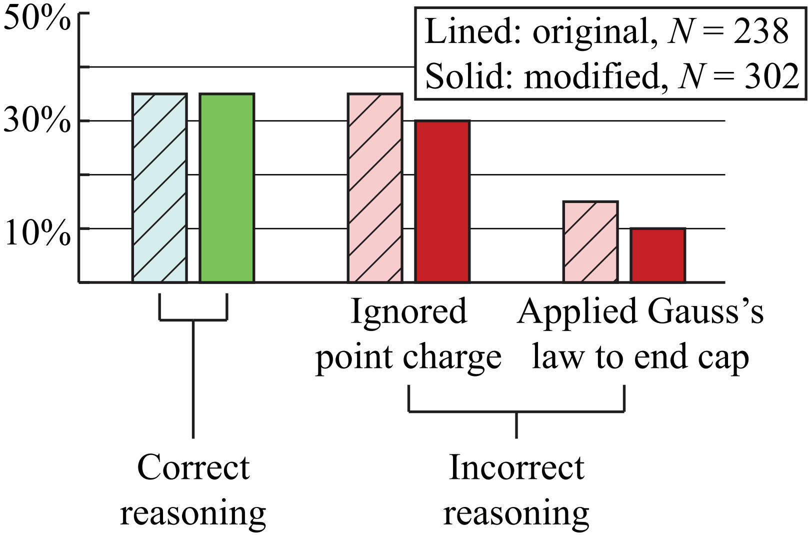


Question: Does Φ_L *increase*, *decrease*, or *remain the same*?

[1] Kanim, S. (1999)

Impact of changes



With the new *Flux and Gauss's law* tutorial:

- Students were about equally-well prepared
- Reduced class time:
  We did ~~more~~ the same with less!
- Made room to cover more topics

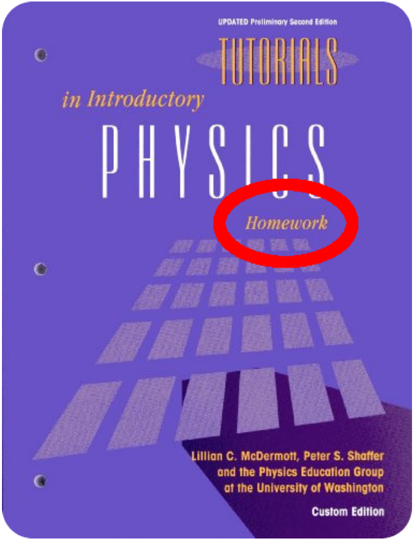
Next steps

- Further validation of flux and Gauss's law
- Optimize time spent/condense more tutorials:
  - Forces & Newton's second and third laws
  - Lenz's law & Faraday's law

Next steps

PhET INTERACTIVE SIMULATIONS

+



Thank you for coming!

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Other UWPEG members:

- Lillian McDermott
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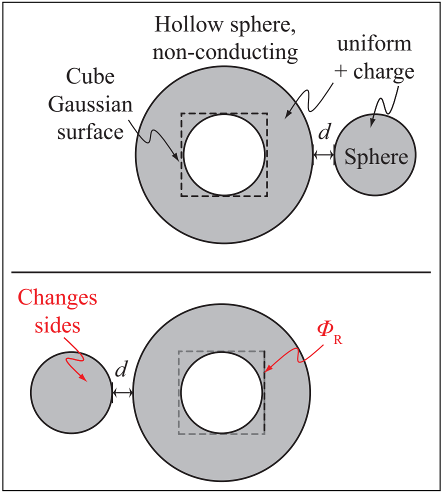
- Paul Emigh
- Alexis Olsho
- Bert Xue
- Tong Wan
- Sheh Lit Chang
- Lisa Goodhew

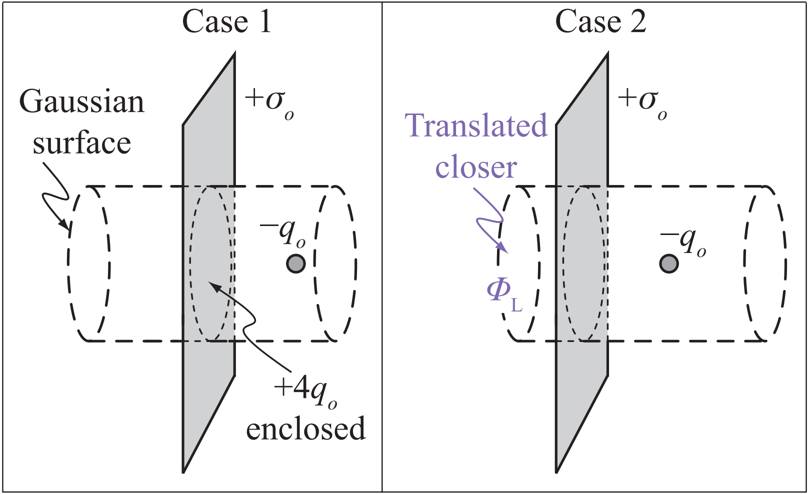
Exam questions

Older conceptual question: $N = 238$



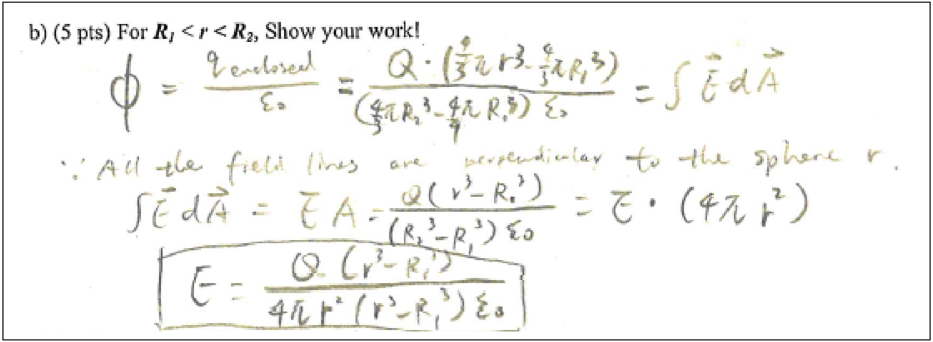
Exam questions

Newer conceptual question: $N = 302$



Exam responses

Initial calculation question (E in thick charged shell): $N = 308$



b) (5 pts) For $R_1 < r < R_2$, Show your work!

$$\phi = \frac{q_{enclosed}}{\varepsilon_0} = \frac{Q\cdot(\frac{4}{3}\pi r^3 - \frac{4}{3}\pi R_1^3)}{(\frac{4}{3}\pi R_2^3 - \frac{4}{3}\pi R_1^3)\,\varepsilon_0} = \int \vec{E}\, d\vec{A}$$

∵ All the field lines are perpendicular to the sphere r.

$$\int \vec{E}\, d\vec{A} = EA = \frac{Q(r^3 - R_1^3)}{(R_2^3 - R_1^3)\,\varepsilon_0} = E\cdot(4\pi r^2)$$

$$E = \frac{Q\,(r^3 - R_1^3)}{4\pi r^2\,(r^3 - R_1^3)\,\varepsilon_0}$$

Exam responses

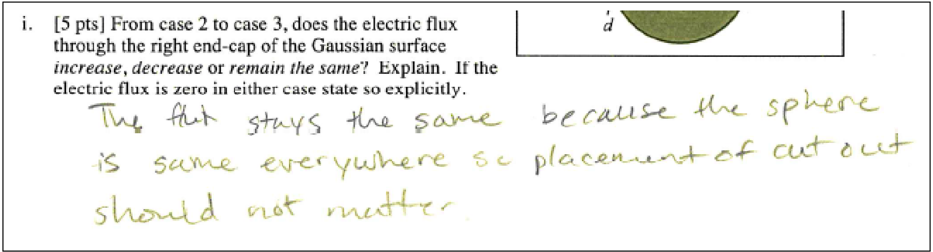
Correct explanation

i. [5 pts] From case 2 to case 3, does the electric flux through the right end-cap of the Gaussian surface *increase*, *decrease* or *remain the same*? Explain. If the electric flux is zero in either case state so explicitly.

the area vector is defiend to point out of the closed surface. and the moved spere has a positive charge so the electri field point out of it. however, in case two the area and the electicfield were in opposite directions, ⊖ flux. Case 3 ⊕ flux therefore, increases

Exam responses

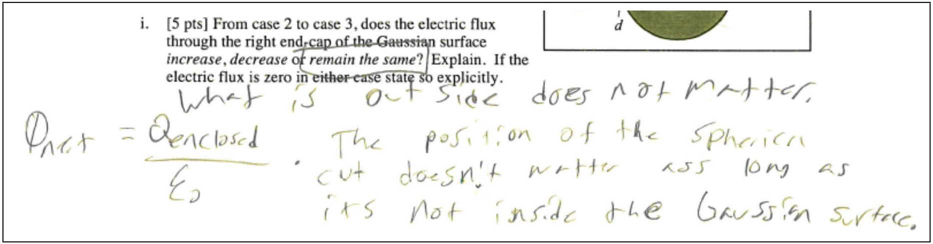
“Ignored point charge” explanation


i. [5 pts] From case 2 to case 3, does the electric flux through the right end-cap of the Gaussian surface *increase*, *decrease* or *remain the same*? Explain. If the electric flux is zero in either case state so explicitly.

The flux stays the same because the sphere is same everywhere so placement of cut out should not matter

Exam responses

“Applied Gauss’s law” explanation



i. [5 pts] From case 2 to case 3, does the electric flux through the right end-cap of the Gaussian surface *increase*, *decrease* or *remain the same*? Explain. If the electric flux is zero in either case state so explicitly.

What is outside does not matter.

$\Phi_{net} = \frac{Q_{enclosed}}{\varepsilon_0}$. The position of the spherical cut doesn't matter as long as its not inside the Gaussian surface.