APPENDIX C: CUE GRADING RUBRIC

This document is not to be used for grading the CUE. In order for scores generated using this rubric to be compared to the results discussed above, graders must go through a calibration exercise. The full training packet can be accessed by contacting Steven Pollock at steven.pollock@colorado.edu.

Using the rubric:

- Partial points are given as (+), starting from zero, up to the maximum points for the question. In most cases, (+) points are indicating partial credit assignments for different pieces of the answer.
- Mistake codes enable us to determine what the most common student errors are in a class. There is often a code for a common mistake, but if a student response does not fit one of these common mistakes, there is no need to use a code.
- When assigning partial points that are not indicated on the rubric, consider how "far" towards the correct answer the student response is. Out of 3 points, for example, 1 point would be "mostly wrong but there is something that is correct,", 2 points would be "mostly correct but there is something that is wrong."
- For all questions, subtract up to 1 point for wrong statements at your discretion. (Eg., for Q7 (pretest Q3) if a student writes "Use Gauss' Law with $Q_{total} = 4/3(\pi r^3 \rho)$ " you may wish to take up to a point off for that incorrect statement of Q_{total} .
- When the rubric says that a certain item is "not graded" (e.g., Q9 "correct") then that item is recorded but does not count towards the final CUE score.

Only give credit for what is actually written on the paper! Don't fill in gaps for the students because you know the answer and think you know where they were going with it. Unlike an exam that is for a grade, this diagnostic is intended to determine student understanding, and so it is not necessary to give credit for a students' intentions or possible understanding.

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Correct	3 points	Correct answer is separation of variables.
Answer		Full credit for Laplace's Equation
		+ 2.5 for "Legendre polynomials"
		+2 point if <i>implies</i> sep. of var. without being explicit
Explanation	2 points	Typically give full credit.
Mistake		A – integrate or direct integration
Code		B – Gauss
		C - N/A
		D - E = -grad V
		X – Blank
		Z – "Don't know"

Q1 (V of theta). 5 points total.

Q2 (cube). 5 points total. Pre-test Q1.

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Correct	3 points	Correct answer is direct integration or Coulomb's Law.
Answer		+1 point if they say that it's a dipole/multipole
Explanation	2 points	Full credit requires some mention of what the integral would look like or a correct statement of why they chose this method. +0.5 for a poor explanation of how they would go about it (eg., writing down Coulomb's Law).
Mistake		A - N/A
Code		B – Gauss
		C – Separation of variables
		D – Multipole
		X – Blank
		Z – "Don't know"

Q3 (cube far away). 5 points total.

Correct	3 points	Correct answer is multipole expansion using the dipole component.
Answer		+1 point if say direct integration
		+ 2.5 for dipole only
		+0.5 for approximation or multipole
		+ 2 for multipole only
		+ 1 for dipole or + 1 for approximation
Explanation	2 points	Full credit for saying dipole dominates because the observation point is
		far away.
		1.5 points for "multipole because r>>a"
		+1 point if said that it's a dipole but give no further explanation
		+1 point if mention higher order multipoles (but not a dipole)
		+0.5 for saying the integration is hard because P is off-axis.
		If they answered direct integration, full credit requires some mention of
		what the integral would look like or why they chose this method. +0.5
		for a poor explanation of how they would go about it (eg., writing down
		Coulomb's Law).
Mistake		A – Integrate or direct integration
Code		B – Gauss
		C – Separation of variables
		X – Blank
		Z – "Don't know"

Correct	3 points	Correct answer is method of images.
Explanation	2 points	 +2 for "must match V=0 at boundary" or "match boundary conditions" +1 for "opposite charge -Q" +1 for mentioning that Q must be on the other side of the wall. Look for marks on the illustration as well.
Mistake Code		A – Integrate or direct integration B – Gauss C – Separation of variables X – Blank Z – "Don't know"

Q4 (images). 5 points total.

Q5 (superposition). 5 points total. Pre-test Q2

Corroct	2 points	Correct answer is supernecition
Correct	5 points	
Answer		0 points for only saying Gauss' Law.
		+1 point for saying integration or dipole
		+1 point for superposition of charges but not fields (e.g. for $4/3 \pi$ (R ³ -
		$r^{3} ho_{0} ho$
		0 for "total charge of sphere with cavity"
Explanation	2 points	Full answer is superposition of two oppositely charged spheres and
		then Gauss' Law to solve for E of each sphere. Need to indicate what is
		being superposed for full credit (e.g., an antisphere of negative charge
		density).
		+1 point for stating what is superposed – two oppositely charged
		sphere (+0.5 point if they don't state the spheres are <i>oppositely</i>
		charged)
		+1 point for explaining how to solve using the two charged spheres
Mistake		A – Integrate or direct integration
Code		B – Gauss
		C – Separation of variables
		D – Use total Q of sphere
		X – Blank
		Z – "Don't know"

Q6 (current loop). 5 points total.

Correct	3 points	Correct answer is multipole expansion using the dipole approximation.
Answer		+1 points for saying Biot-Savart or integration
		+ 2.5 for mentioning "dipole"
		+0.5 for also mentioning approximation or multipole
		+ 2 for mentioning "multipole"
		+ 1 for also mentioning dipole or approximation
Explanation	2 points	Full credit for saying that it looks like a dipole because P is far away.
_	_	1.5 points for "multipole because r>>a"
		+1 point for only saying dipole (without mention of distance), or vice
		versa.
		+0.5 point for mentioning that the integration is hard because P is off-
		axis
		If they answered Biot-Savart, full credit requires some mention of what
		the integral would look like or why they chose this method. +0.5 for a
		poor explanation of how they would go about it (eg., writing Biot-Savart
		Law).
Mistake		A – Integrate or direct integration or Biot-Savart
Code		B – Gauss

C – Separation of variables
X – Blank
Z – "Don't know"

Q7 (gauss). 5 points total. Pretest Q3

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Correct	3 points	Correct answer is Gauss' Law
Answer		+1 point for saying direct integration
Explanation	2 points	 Full credit requires some explanation of why (not just how) Gauss' Law is used. This would include some mention of the Gaussian surface used or the symmetry (such as charge distribution depends only on "r", or E field is radial). +1 point if the correct Gaussian surface is drawn. +0-1 point for explaining how to solve by Gauss's Law. If answer "direct integration" must give explanation of how they would solve this integral +0.5 for a poor explanation of how they would go about it (eg., writing down Coulomb's Law).
Mistake		A – Integrate or direct integration
Code		B - N/A
		C – Separation of variables
		X – Blank
		Z – "Don't know"

Q8 (delta function). 5 points total.

Value of	3 points	Correct answer is m ₁ +m ₂ .
integral		+1.5 points for 4π m or some variant.
		0 points for 4π mr or 4π mr ² , m δ^3 (r-r ₁) or some variant (wrong units)
Physical	2 points	Correct answer is two point masses of mass m ₁ and m ₂ . Full credit given
situation		for just saying two point masses.
represented		0 points for two spheres or two shells
		0.5 for two of something (but not spheres, shells, or masses)
		1 for a single point mass
		1 point for two masses (without saying that they're points).
Mistake		A – Two spheres
Code		B – Three charges or masses
		C mr or mr ² or some variant
		D – A and C
		E – single charge or mass
		X – Blank
		Z – "Don't know"

Q9 (reference for V). 10 points total. Pretest Q4

Correct	Not	0 for A, C, or D	
answer	graded.	1 for B (correct answer)	
Notes:	Some common answers:		
	+6 for "V d	ecreases as you move away" or "increases as you move towards"	
	+2 for ex	xplicitly mentioning positive charge	
	+1 for al	so having the answer right	
	There are t	hree main approaches to this problem: Potential, work, and energy. We	
	break the a	nswers into those three approaches. <i>In all cases</i> subtract -1 for each	
	completely	wrong statement (up to 2)	
POTENTIAL	APPROACH		
A) The	4 points	Since ρ is positive:	
physics of		ΔV is positive OR V(r=0) > V(∞)	
positive		+2 if don't explicitly state that this is because the charge is positive.	
charges			
B)	4 points	ΔV is defined as:	
Definition		$V(ref)-V(r) OR V(r=0) - V(\infty) OR Vf-Vi$	
of potential		OR "V decreases as you move away"	
difference		OR V(r=0) > V(∞) (nb. Statement gives points for A and B).	
		+2 for noting that usually $V(\infty) = 0$ and it is "shifted".	
C) Logic	2 points	And since $V(r=0)=0$ THEN $V(\infty) = XXX$. (Students get credit for logic if a	
		sign error is introduced from A or B).	
		+1 for having correct answer without explicitly stating logic.	
WORK/ENEF	RGY/FORCE	APPROACH	
A) The	4 points	Since ρ is positive, it takes positive work to bring a positive charge from	
physics of		infinit OR that a test charge would be repelled.	
positive		+2 if don't explicitly state that this is because the charge is positive.	
charges			
B)	4 points	It takes positive work to bring positive charge from low to high V.	
Definition		If they state $W=Q\Delta V$ they must make it clear what ΔV is defined as, or	
of potential		what direction you're moving (infinity to origin) in going through ΔV .	
difference		OR "V decreases as you move away"	
and		+2 for noting that usually $V(\infty) = 0$ and it is shifted	
connection			
to work			
C) Logic	2 points	Since $V(r)=0=0$ then positive work implies $V(\infty) < V(r=0)$ and negative	
		numbers are less than zero.	
		+1 for having correct answer without explicitly stating logic.	
ELECTRIC FI	ELD APPROA	ACH	
A) The	4 points	E field lines radiate out (no need to explicitly say positive charges)	
physics of		OR E goes from high to low V	
positive			
charges			
B)	4 points	$\Delta V = - \int E \cdot dl$ where <i>dl</i> is directed towards sphere AND E field lines	
Definition		v radiate out (nh Students get credit for this statement in A and P)	
of potential		OR F goes from high to low V (full credit for R)	
difference			
C) Logic	2 points	And since $V(r=0)=0$ then $V(\infty)$ is negative.	
		+1 for having correct answer without explicitly stating logic.	
Mistake		A, C, D – chose answer "A", "C" or "D" as appropriate	
Code		X – Blank	
		Z – "Don't know"	

Q10 (sketch E cylinder). 10 points. Pretest Q5

V	,	
Charge	3 points	+1.5 for correct sign (positive on top)
distribution		+1 for charge residing on surface only (Q=0 inside cylinder)
		+ 0.5 for nonuniform distribution with charge concentrated at the poles
		(give full credit unless diagram <i>clearly</i> shows a uniform distribution)
E inside	3 points	Full credit given if E=0 inside (whether explicitly stated, or drawn with
cylinder		no field lines inside).
		No credit if E=0 everywhere.
E outside	4 points	See below for grading rubric for common answers.
cylinder		+1 for an E that is approximately perpendicular to surface (or at least
		not <i>not</i> perpendicular)
		+1 for going to E_0 far away from cylinder
		+2 for field lines starting on + and ending on – charges
		-1 for no evidence of E_0 (see B and E)
		0 if the field looks like E ₀ everywhere outside
Mistake		A – 1 pt - E is "expelled" like a magnetic field
Code		B – 2 pt - looks like dipole (as if external E not present)
		C – 0 pt - E constant everywhere outside
		D – 0 pt - E constant everywhere inside and outside
		E – 0 pts - E radial outwards
		X – Blank
		Z – "Don't know"



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V	3 points	Full credit for $V(r=R)$ =constant or $V(r=R)=0$ or $V_{in}=V_{out}=0$ (or
		constant).
		+1.5 for V=0 for r <r< th=""></r<>
		+1.5 for $V_{in}=V_{out}$ (with no mention of value)
		<i>Note</i> V_{below} and V_{above} are satisfactory equivalents for V_{in} and V_{out} .
		Continuity of E _{parallel} is satisfactory equivalent.
		+1 for E _{perp} is continuous
Е	3 points	Full credit for E_{out} - E_{in} = + σ/ϵ_0 or equivalent (such as
		$\partial V_{out} / \partial n - \partial V_{in} / \partial n = -\sigma / \varepsilon_0$ or discontinuity in E _{perpendicular}).
		+0.5 for only mentioning E=0 inside
		+1 for mentioning E=0 inside and mentioning discontinuity at the
		surface
		+1.5 for just writing $\partial V/\partial r = -\sigma/\varepsilon_0$
		+1 for E _{parallel} is discontinuous
		-0.5 for a sign error
Mistake		A – gave a value for E instead of boundary condition.
Code		B – said that E is continuous or $E_{in}=E_{out}$
		C – said that the derivative of E is discontinuous or V is discontinuous
		D – only gave one condition
		X – Blank
		Z – "Don't know"

Q11. 6 points. (BC's on E and V)

Q12 (graph E and V of disk). 22 points. Pretest Q6

Q12 Part A. 2 points.

A Value of	2 point	Full credit for $\sigma/2\varepsilon_0$ (or $2\pi\sigma$)
E near disk		+1 for σ/ϵ_0 (or $\pi\sigma$)
		+ 0.5 for the same E as an infinite plane
		+0.5 for E = constant or E=0

Q12 Part B. 2 points.

B Behavior	2 points	Full credit for kq/r ² or 1/r ² or 1/z ²
of E near	_	+1 for "point charge"
infinity		0 for "goes to zero"

Q12 Part C (graph E of disk). 9 points.

If a student draws field lines for Q12C or Q12D, grade this question based on those field lines to the best of your ability.

Antisymme	3 points	Full credit if E is not symmetric (ie., E is negative for negative z)
try of E		
field		
Behavior of	3 points	Full credit if it drops towards E=0 far away with a behavior that looks
E at infinity		like $1/z^2$.
		-1 for any increase in E while moving away from disk (as in C below)
Behavior of	3 points	Full credit for a finite value that is not zero or infinity (though the full
E at origin		answer is $\sigma/2\varepsilon_0$). The graph does <i>not</i> need to look flat at the top
		(mathematica shows that the range of "z" in which E is constant is very
		small)
		-1 for a graph that has incorrect signs (a negative value for Ez>0 and a

	positive value for Ez <1.
Mistake	This problem is easiest to grade based on the way that the students
Code	graph appears. Below are mistake codes which correspond to different
	graphing mistakes. Following each code is the correct point assignment.
	For example, (0,3,0) represents "0" for antisymmetry, "3" for infinity, and
	"0" for origin.
	A – Point charge $(0,3,0)$
	B – Symmetric disk (0,3,3)
	C – Two humps (3,2,0) but (3,1,0) if shows E=0 at a finite value of z
	D – One hump (0,3,3)
	E – Antisymmetric point charge (3,3,0)
	F – Antisymmetric disk (3,3,3). Same points & code for a sketch that looks
	like "D" but antisymmetric about the origin.
	G – Only graphed + z range.
	X – Blank
	Z – "Don't know"



Q12 Part D (graph V of disk). 9 points.

Symmetry	3 points	V should be symmetric about the origin
of V		
Behavior of	3 points	V should drop to zero, looking like 1/r (or explanation includes
V at infinity		mention of 1/r).
		-1 if looks linear everywhere
		-1 if really looks like 1/r ² (comparing to their E field)
Behavior of	3 points	Full credit for a kink at z=0.
V at origin		+2 for finite, nonzero value at $z=0$ (but no kink). Zero value OK if

	 going to finite value at infinity. 0 points if V is constant everywhere. -2 for a negative value or negative infinity. Negative value OK if decreasing towards a finite negative value at infinity.
Consistent 0 points with E	0 points if consistent; -1 point for an inconsistency in the symmetry
Mistake Code	This problem is easiest to grade based on the way that the students graph appears. Below are mistake codes corresponding to different graphing mistakes. Following each code is the correct point assignment. For example, (0,3,0) represents "0" for antisymmetry, "3" for infinity, and "0" for origin. <i>Be sure to subtract a point from symmetry and origin if it's</i> <i>inconsistent with E.</i> Sketches on next page. A – Inconsistent with E B – Same as E C – One hump (3,3,2) D – Disk (correct answer) (3,3,3) E – Point charge (3,2,3) G – Antisymmetric; (0,3,3) for finite value at z=0; (0,3,0) for infinite value at z=0 H – Bowl (3,0,0) X – Blank Z – "Don't know"



Q13 (Cartesian BC's). 5 points.

Correct	Not graded	0 for B or C
answer	_	1 for A (correct answer)
Score for	5 points	Must have correct answer and reasoning for full credit. Correct
problem		reasoning includes saying that sin=0 at two places and this matches
		the boundary conditions. Must also include the fact that the
		exponential solutions will not match the boundary conditions.
		The pieces of a correct answer are:
		+4 that sin/cos are zero in two places, which matches boundary
		conditions
		+1 for exponentials don't match the boundary conditions
		Some common wrong answers are:
		+1 if only say that sin(x=0)=0
		+1 for right answer with <i>some</i> reasoning, but poor reasoning
		+1 for "D=0 with sin/cos"
		+1 For stating that the boundary conditions in the x direction are
		homogenous.
		+2 for "easier/convenient to match x to sin/cos," or "periodic in x"
		0 point for restating boundary conditions

Q14 (Dielectric). 8 points.

Describe	4 points	Full credit requires that they mention that the dielectric polarizes,
what	_	giving rise to bound charge on the surfaces.
happens to		<u>Polarization (max +2, min 0):</u>
the		+2 for either saying the dielectric polarizes or correctly describing the
dielectric.		microscopic process of polarization or for a drawing clearly
		illustrating polarization
		<u>Bound charge (max +2, min 0):</u>
		+2 for bound charge on the surfaces
		-0.5 for describing bound charge of the wrong sign,
		-1 for indicating that mobile charge are free to move (or just -0.5 if
		fail to say "bound")
		+1.5 for drawing with charges shown on top and bottom surfaces w/o
		specifying they are bound
		+/- 0 pts for indicating bound volume charge (can't be determined)
Limiting	4 points	+2 for E=0 inside (+0.5 for "E decreases" without limiting value)
values of		+2 for bound charge is equal to sigma (+0.5 for "sigma increases")
charges and		+1 for writing only "same as in conductor"
net E-field		
Mistake		A – E increases in dielectric
Code		B – bound surface charge goes to infinity
		C – Draw charges but don't specify they are "bound"
		X – Blank
		Z – "Don't know"

Q15 (Circle BC)

Score	5 points	+2.5 points for a correct answer (I or III)
		-2.5 points for an incorrect answer (II or IV)
		no + or – for "one of these two" without clear choice
		(Minimum zero points)
Mistake		A – chose II (plus one correct answer)
Code		B – chose IV (plus one correct answer)
		C – chose II and IV
		X – Blank
		Z – "Don't know"

Q16 (Multipole). 5 points.

Correct	Not graded	0 non-zero dipole moment
multiple	_	1 dipole moment is zero (correct answer)
choice		
Score	5 points	A complete answer is that there are two or four oppositely directed dipoles (+2.5) and the addition of the two dipole moments gives zero (+2.5). (The fact that it's a quadrupole does not prove the dipole moment is zero). Also full credit for stating that it is a pure quadrupole and so that is the only term in the multipole expansion. Partial points for the following wrong answers: +2.5 for only saying it's two opposite dipoles or the superposition of two dipoles +0 for Q=0 +1 for saying it's a quadrupole (with no other explanation) +3 for saying that the quadrupole is the first term in the multipole expansion and thus the dipole moment is zero +1 for saying something about the sum of charge and distance (without explicitly saying that the dipole moment is zero by this calculation)
Mistake		A – Quadrupole
Codes		B – No net charge
		X – Blank
		Z – "Don't know"

Q17 (Ampere). 7 points. Pretest Q7

Correct	2 points	Full credit for saying that B is maximum at the edge of the cylinder
Reason	5 points	A full explanation is that I _{through} is maximum at the radius, and ∫B•dl gets larger as you move away from the cylinder. Full credit for showing graph of B for all r (linear inside cylinder and drops as 1/r outside, continuous at surface). +3 for I _{through} is maximum +2 for ∫B•dl increases as you move away +1 only if they just say that it goes as 1/r outside or simply invoke the right hand rule +1 for only mentioning or writing Ampere's Law +1-2 for saying "surface" with a poor explanation
Mistake		A – B decreases with distance
Code		B – right hand rule
		C- B max in center of wire
		X – Blank
		Z – "Don't know"