APPENDIX A: PROBLEM CARDS (Translated from Dutch)

1. Electricity

		Assignment + ***elaboration***
Gauss	1em	Consider two long concentric conducting cylinders, with radius *a* and 4*a* respectively. In between the cylinders, the electric field amounts to $\vec{E} = \beta r^3 \vec{e}_r$ ($\vec{e}_r$ is the unit vector, perpendicular to the cylinder axis). Compute the spatial charge density in the space between the cylinders. *The field outside a cylinder symmetric charge distribution is equal to the field of a line charge*
	3em	An electric field points along the positive x-axis. The magnitude of the field is $\vec{E} = (bx^2 + c)\vec{e}_x$. What is the total charge in a cube enclosed by the planes $x=0$, $x=a$, $y=0$, $y=a$, $z=0$ en $z=a$? *The flux through a plane parallel to the electric field is zero*
	10em	Compute the field between two concentric spherical shells, carrying charges Q_1 and Q_2 respectively *The field inside a charged spherical shell does not depend on the charge on the shell*
	15em	What is the electric field in between the plates of a parallel-plate capacitor. The surface area of the plates is *A*, the plates are separated by a distance *d* en the plates hold charges *Q* and –*Q* respectively. *Inside a capacitor, the field component parallel to the plates is negligible*
	17em	Compute the field of an infinite flat slab of charge *The only field component of an infinite plane charge is perpendicular to the plane*
	19em	Prove that within a conductor, the net enclosed charge inside any closed surface is zero, even if the conductor has holes with charge distributions inside. *The field in a conductor is zero everywhere*
Image charges	2em	An uncharged metal sphere of radius *R* is at a distance *r* from a point charge *q*. What is the force between the charge and the sphere? *The charge distribution on the metal object is influenced by a nearby charge*
	7em	What is the potential difference between a grounded flat metal sheet and a uniformly charged sphere carrying a charge *q* at a distance *r* above the surface? *The field is the sum of contributions by the charge and the image charge*
	12em	A wire carrying a charge *q* per meter runs parallel to a grounded metal sheet of infinite dimensions. What is the field? *Metal is a conductor*
	16em	A small sphere, mass 2 [gr] and charge 6 [mC] is attached to a massless insulating cord of length 50 [cm], suspended at 5 [cm] from a large vertical grounded metal plate. What will be the distance between the sphere and the plate? *A charge nearby a metal plate influences an image charge*
	20em	Take a large grounded metal plate bent at an angle of 90°. A point charge is placed close to the inner corner, at 2 [cm] distance from the surface in both directions. What is the force on the point charge? *A nearby charge influences the charge distribution on the plate*
Dipole approxi	4em	Two isolating spheres of radius *R* carry opposite, homogeneously distributed, charges *q* and -*q*. The distance between the spheres is 5*R*. What is the field of the configuration at a distance $r \gg R$. *The field outside a charged sphere is equal to the field of an equal point charge*

	6em	Take two point charges *q* and -*q*, with a short distance $\vec{d}$ between them. What is the field at a long distance $\vec{r}$. *Seen from a large distance, the distance between the point charges seems negligibly small*
	8em	What is the torque on a dipole $\vec{p}$ oriented at an angle perpendicular to the electric field $\vec{E}$. *The dipole moment is the product of a charge q and a distance l, with l being small and q being large*
	13em	Consider two dipoles $\vec{d}$ oriented along the same line, in opposite directions, at a distance *x* from each other. What is the total energy? *Potential energy of a dipole in an electric field is the limit of the sum of energies over the individual charges.*
	14em	Consider two parallel thin metal cylinders of opposite charges Q and -Q. Each cylinder has a length of 1 [m] and the distance between the cylinders is 1 [mm]. What is the field in a point at 1 [m] from the wires in the plane perpendicular to the wires. *The opposite charge densities on the cylinders result in dipole density*
Coulomb's law/Superposition	5em	Consider two point charges q and -q, placed in the origin and at a distance $\vec{R}$ from the origin respectively. What is the total field at a distance $\vec{r}$ from the origin($\|\vec{r}\| \approx \|\vec{R}\|$). *The field of two charge distributions is the sum of the individual contributions*
	9em	What is the field on the axis of a charge ring. Charge *q*, radius *r*. *At the axis of the ring, the only component of the field is directed along the axis*
	11em	What is the field of a line of charge extending along the entire positive x-axis at a charge density λ *A half infinite line charge is not symmetric under translation*
	18em	A test charge q is in the middle above a uniformly charged surface of charge density σ. The, square, surface has sides *r*. The charge is at a distance 2*r* from the center of the surface. What is the force on the charge in the field of the plate? *The field of a square surface has components in all directions*

2. Magnetism

Ampère's law	3bm	Two long concentric solenoids of radius *r* and $\sqrt{2}.r$ respectively, both have N turns per meter. The inner coil carries a current *I*, the outer coil carries 2*I* in the opposite direction. What is the total magnetic field at the axis. *A long solenoid has a uniform magnetic field at the inside*
	8bm	An infinite flat surface carries a uniform current density. What is the magnetic field above the surface *The field of an infinite flat surface does not vary with distance*
	13bm	Take a circular surface current running over a cylinder of infinite length. Find the magnetic field B everywhere in space. *The outside field of an infinitely long solenoid is zero.*
	16bm	A cylinder of radius *R* carries a uniform spatial current, at a current density *j*. Find the magnetic field inside the cylinder as a function of the distance from the axis. *Magnetic fieldlines run perpendicular to the direction of the current*
	18bm	A toroid coil of *N* turns carries a current *I*. The dimensions of the coil are d_1 (overall radius) and d_2 (radius of a turn), with d_1 very large compared to d_2. Find the field inside the windings, at a given current *I*. *The magnetic field of a toroid coil has rotational symmetry*

	20bm	The, magnetic field inside a long vertical tube is axially directed, The field strength amounts to $\vec{B}(r) = B_0(1 - r^2 / R^2)\vec{e}_z$, with *r* the distance from the axis, and *R* the radius of the tube. Outside the cylinder, the field is zero. Find the current density $\vec{J}(r)$ inside the tube. *The current density in the tube is perpendicular to the magnetic field*
Dipole approximation	1bm	Two short solenoid coils, radius *r* and *N* turns each, are in the same plane. The axis of each coil is perpendicular to the plane. Each coil carries a current *I*, the distance between both coils is *d*, with *d*>>*r*. Find the torque on each of the coils. *Torque is the cross product of the magnetic moment of the coil with the external B-field*
	7bm	A square wire frame carries a current *I*, what is the B-field in an arbitrary point at a long distance from the frame *At a long distance the exact shape of the frame does not matter*
	12bm	A small circular wire loop, radius r, lies in the xy-plane. The loop carries a current *I*, parallel to the xy-plane. The externally applied magnetic field amounts to: $\vec{B} = a^x.\vec{e}_x$. What is the force on the wire loop? *With a small wire loop, the field is constant over the loop.*
	14bm	Two uniformly charged circular disks (radius r, charge q), revolve on a shared axis at an angular velocity ω. The disks are separated by a distance of 10r. What is the energy difference is the disks rotate in the same direction versus if they rotate in opposite directions. *A rotating charged disk has a magnetic momentum.*
	17bm	Two magnetic dipoles each have a dipole moment $\vec{p}$. One dipole in in the origin, aligned with the z-axis, the other is at a distance r along the y-axis, and is oriented perpendicular to the first. What is the force between both dipoles? *Magnetic dipoles at an angle exert a torque.*
Induction/flux	2bm	A solenoid, radius r, length l, and N turns, revolves at angular velocity ω in a uniform magnetic field. The axis of rotation is perpendicular to the field. What is the induced potential difference? *The rotation changes the flux through the coil*
	4bm	A metal bar revolves around its end. The magnetic field in space is parallel to the rotational axis. What is the potential difference across both ends of the bar? *Changing flux in an –imaginary– circuit leads to an induced potential difference.*
	6bm	A square wire frame (resistance *R*) in the xy-plane moves in the x-direction at a certain speed, its position changes according to $x(t) = v.t$. A current runs through an infinitely long wire along the y-axis. Find an expression for the current that runs in the wire frame as a function of time. *The flux through the wire frame solely depends on the distance from the wire*
	9bm	A circular wire frame (radius *r*, resistance *R*) is aligned with the xy-plane, the magnetic field is $\vec{B} = a \sin bt \cdot \vec{e}_z$. What is the current in the wire, as a function of time? *If B varies with time, the flux through the ring will also vary*
	19bm	A rectangular wire frame (height 4*a*, width 2*a*) and an infinitely long vertical wire are in the same plane. The wire runs parallel to the long side of the wire frame. What is the mutual inductance between wire and wire frame? *A current in the wire yields a flux through the wire frame*
Biot-Savart's	5bm	Take a circular wire frame of radius *r*. What is the magnetic field on the axis of the frame as a function of the current in the frame and the distance from the centre? *On the axis of a cylinder symmetric current, the only field component is aligned along the axis*

	10bm	A rectangular wire frame carries a current I. What is the magnetic field B in an arbitrary point in space? *The total field is the sum of all individual contributions*
	11bm	A closely wound flat coil has N turns. The radius of the innermost turn is r, the radius of the outermost turn is $2r$. All turns are in the same plane. What is the magnetic field B in the centre of the coil? *The magnetic field B in the centre of the coil is directed along the axis of the coil.*
	15bm	A very long wire runs along the x-axis to the origin, makes a turn of 90° and continues along the positive y-axis. What is the field in a point in the xy-plane expressed as a function of x, y and I? *The total field is the sum of the contributions by both straight wire lengths*

APPENDIX B: EXPERT SORTINGS

The matrices below represent the joint occurrences for each possible problem pair in the problem sortings of the three external experts.

1. Electricity problems

		1	3	10	15	17	19	2	7	12	16	20	4	6	8	13	14	5	9	11	18
Gauss' law	1	3	3	2	2	2	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	3	3	3	2	2	2	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	10	2	2	3	3	3	2	0	0	1	0	0	0	0	0	0	1	0	0	1	0
	15	2	2	3	3	3	2	0	0	1	0	0	0	0	0	0	1	0	0	1	0
	17	2	2	3	3	3	2	0	0	1	0	0	0	0	0	0	1	0	0	1	0
	19	2	2	2	2	2	3	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Image charges	2	0	0	0	0	0	0	3	2	2	2	3	0	0	0	0	0	0	0	0	2
	7	0	0	0	0	0	0	2	3	2	1	2	0	0	0	0	0	0	0	0	1
	12	1	1	1	1	1	1	2	2	3	1	2	0	0	0	0	1	0	0	0	1
	16	0	0	0	0	0	0	2	1	1	3	2	0	0	0	0	0	0	0	0	2
	20	0	0	0	0	0	0	3	2	2	2	3	0	0	0	0	0	0	0	0	2
Dipole approximation	4	0	0	0	0	0	0	0	0	0	0	0	3	3	2	2	2	2	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	3	3	2	2	2	2	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	2	2	3	3	1	1	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	2	2	3	3	1	1	0	0	0
	14	1	1	1	1	1	1	0	0	1	0	0	2	2	1	1	3	2	0	0	0
Coulomb's law/ spuerposition	5	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	2	3	1	1	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	1
	11	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	3	1
	18	0	0	0	0	0	0	2	1	1	2	2	0	0	0	0	0	0	1	1	3

2. Magnetism problems

		3	8	13	16	18	20	1	7	12	14	17	2	4	6	9	19	5	10	11	15
Ampère's law	3	3	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	1	3	1
	8	0	3	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	3	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	2	2	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	3	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	1	3	1
	20	0	1	1	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dipole approximation	1	0	0	0	0	0	0	3	0	3	2	2	0	2	0	0	0	0	0	0	0
	7	1	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	3	3	1	3
	12	0	0	0	0	0	0	3	0	3	2	2	0	2	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	2	0	2	3	1	0	2	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	2	0	2	1	3	0	1	0	0	0	0	0	0	0
Induction/ flux	2	0	0	0	0	0	0	0	0	0	0	0	3	1	3	3	2	0	0	0	0
	4	0	0	0	0	0	0	2	0	2	2	1	1	3	1	1	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	3	1	3	3	2	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	3	1	3	3	2	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	3	0	0	0	0
Biot-Savart's law	5	1	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	3	3	1	3
	10	1	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	3	3	1	3
	11	3	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	1	3	1
	15	1	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	3	3	1	3

3. Expert labels

Overview of all labels used by the experts. Numbers between parentheses indicate the number of experts using this label.

Electricity	Magetism
Coulomb	Ampère's law
Compute field by integration	Spatial current
Superposition charge	Surface current
Force equilibrium	Magnetic field with current density
Forces	Coils (2x)
Dipole (3x)	Biot Savart
Superposition and dipole	Force on infinitesimal current element in field
Gauss (3x)	Wire, current, integrate Biot-Savart
Gauss differentiate	Current superposition with integration
Gauss integrate	
	Dipoles
Image charge (2x)	Force and torque
Induced charges	Forces
Proof problem	Inductance (2x)
	Changing flux