Electronic Supplementary Material (ESI) for Environmental Science: Nano.

Supporting Information

Towards resolution of antibacterial mechanisms in metal and metal oxide nanomaterials: a meta-analysis of the influence of study design on mechanistic conclusions

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Table S1. Search terms used to query Web of Science, by core composition. All searches were performed during July 2019. Filters were set to include documents of the type "Article" published as early as 2000 in the English language. "TS" indicates that terms were searched for in the title, abstract, and keywords of papers.

ENM core composition	**Search term**
Cu/CuO	TS=((nano* AND (Cu OR *CuO OR *copper)) AND ((mechanism$ OR mode of OR pathway) AND (*microb* OR *toxic* OR *bacteri*)))
TiO_2	TS=((nano* AND (*TiO2 OR *titanium dioxide)) AND ((mechanism$ OR mode of OR pathway) AND (*microb* OR *toxic* OR *bacteri*)))
Ag	TS=((nano* AND (Ag OR *silver)) AND ((mechanism$ OR mode of OR pathway) AND (*microb* OR *toxic* OR *bacteri*)))
ZnO	TS=((nano* AND (*ZnO OR *zinc)) AND ((mechanism$ OR mode of OR pathway) AND (*microb* OR *toxic* OR *bacteri*)))

Table S2. Full list of study design and conclusion variables within each category (see Table 2 of the main text). The "Variable as Statement" column gives the statement that must apply to a study for the value of the variable in question to be recorded as "positive" for that study. Studies to which this statement does not apply are recorded as "negative" for that variable.

-	Variable Category	Category Notes	Variable Name	Variable as Statement
Study Design Variables	ENM size	dry size, as measured by TEM/SEM	<10nm	The ENMs used were smaller than 10nm in their smallest dimension, as measured by TEM or SEM
			10-20nm	The ENMs used were between 10 and 20nm in their smallest dimension, as measured by TEM or SEM
			20-30nm	The ENMs used were between 20 and 30nm in their smallest dimension, as measured by TEM or SEM
			30-40nm	The ENMs used were between 30 and 40nm in their smallest dimension, as measured by TEM or SEM
			40-50nm	The ENMs used were between 40 and 50nm in their smallest dimension, as measured by TEM or SEM
			50-100nm	The ENMs used were between 50 and 100nm in their smallest dimension, as measured by TEM or SEM
			Compare to >100nm	ENMs were compared to materials of particle size larger than 100nm in their smallest dimension, as measured by TEM or SEM
			Compare multiple	ENMs of multiple sizes were compared in mechanism-targeted experiments
			Unspecified	The size of ENMs was not specified
	Surface coating	applies only to colloidal ENMs	Capped	The ENMs used were coated in a nonmetallic capping or reducing agent
			Uncapped	The ENMs used were (reported to be) uncoated with any nonmetallic capping or reducing agent
			Compare	Coated and uncoated ENMs were compared
			Unspecified	No comment was given on the presence or absence of capping or reducing agents
			Tox control	The antibacterial activity of the capping or reducing agent(s) alone (without ENMs) was assessed during toxicity assessment
			Multiple capping agents	Multiple capping or reducing agents were compared in mechanism-targeted experiments

Surface charge	measured by zeta potential, in exposure medium	Positive	ENMs had a positive surface charge in the exposure media used for mechanistic studies
		Negative	ENMs had a negative surface charge in the exposure media used for mechanistic studies
		Compare multiple	ENMs with different surface charges were compared in mechanistic studies
		Unspecified	The surface charge of ENMs was not specified
Mode of delivery	colloidal or immobilized ENMs	Colloidal	ENMs were colloidal (suspended in liquid)
		Immobilized	ENMs were immobilized (embedded in a matrix or on a membrane)
		Compare multiple	Colloidal and immobilized ENMs were compared in mechanistic studies
		Unspecified	The mode of delivery of ENMs was not specified
Bacterium Gram type		Gram positive	The bacterium used for mechanistic studies was a Gram positive bacterium
		Gram negative	The bacterium used for mechanistic studies was a Gram negative bacterium
		Both	Both Gram positive and Gram negative bacteria were used for mechanistic studies
		Not specified	The bacterium used for mechanistic studies was not specified (or the study was done on a diverse community of many bacteria)
Characterization		SEM/TEM	SEM or TEM was used to characterize the ENMs for this study
		DLS	DLS was used to characterize the ENMs for this study
		Zeta potential	The zeta potential of ENMs was characterized in this study
		XRD	XRD was used to characterize the ENMs for this study
		BET	BET was used to characterize the ENMs for this study
		AFM	AFM was used to characterize the ENMs for this study
		XPS	XPS was used to characterize the ENMs for this study
		UV-Vis	UV-Visible spectroscopy was used to characterize the ENMs for this study
		FTIR	FTIR was used to characterize the ENMs for this study

		ICP or AAS	ICP-MS (or -OES, -AES) or AAS was used to characterize the ENMs for this study
		EDS	EDS was used to characterize the ENMs for this study
		PL Spectroscopy	PL spectroscopy was used to characterize the ENMs for this study
Toxicity assay	the experimental method(s) used to assess the magnitude of antibacterial activity (not the mechanism)	CFU count/plating	A CFU count/plating assay was used to characterize the magnitude of antibacterial activity
		KB/Disk diffusion	The Kirby Bauer/disk diffusion assay was used to characterize the magnitude of antibacterial activity
		Broth microdilution/growth inhibition in liquid media	The broth microdilution assay was used to characterize the magnitude of antibacterial activity
		Membrane	A membrane damage assay was used to characterize the magnitude of antibacterial activity
		Other	Another assay was used to characterize the magnitude of antibacterial activity
		Multiple concentrations	The antibacterial activity of ENMs was assessed at multiple concentrations
		Time points	The antibacterial activity of ENMs was assessed at multiple time points
Lighting	for mechanism-targeted experiment(s)	UV	Mechanism-targeted experiments were conducted under UV illumination
		Visible	Mechanism-targeted experiments were conducted under visible light
		Dark	Mechanism-targeted experiments were conducted in darkness
		Compare multiple	Multiple lighting conditions were compared in mechanism-targeted experiments
		Unspecified	Lighting conditions were not specified
		Control	A negative control (without ENMs) was used in the mechanism-targeted experiment with the same illumination
ENM aggregation	hydrodynamic size, measured by DLS, applies only to colloidal ENMs	<50nm	The hydrodynamic size of ENMs was less than 50nm

		50-100nm	The hydrodynamic size of ENMs was between 50 and 100nm
		100-200nm	The hydrodynamic size of ENMs was between 100 and 200nm
		200-500nm	The hydrodynamic size of ENMs was between 200 and 500nm
		>500nm	The hydrodynamic size of ENMs was greater than 500nm
		Compare multiple	ENMs of multiple hydrodynamic sizes were compared in mechanism-targeted experiments
		Unspecified	The hydrodynamic size of ENMs was not specified
	Mechanism-targeted methods	[name of Group, Approach, or Technique], [name of mechanism question]	This Group/Approach/Technique was applied to answering this mechanism question.
Conclusion Variables		Ion	Metal ions released from particles into the exposure medium are necessary for antibacterial activity
		Contact	Close association between the ENM and cell is necessary for antibacterial activity
		Internalization	Internalization of intact ENMs across an intact cell membrane contributes significantly to antibacterial activity
		ROS	The production or accumulation of ROS, intracellularly or extracellularly, contributes significantly to antibacterial activity
		Photoactivity	The presence of light is essential for antibacterial activity
		Membrane	Damage to the cell wall or membrane contributes significantly to antibacterial activity
		DNA	Damage to bacterial DNA contributes significantly to antibacterial activity
		Protein	The binding or inactivation of intra- or extracellular proteins by ENMs or their dissolved components contributes significantly to antibacterial activity

Table S3. Full list of mechanism-targeted experimental Techniques, categorized according to Group and Approach as explained in Table 4 of the main text.

Group	Approach	Technique		Endpoint	Type of Analysis	Used For	References
1	1	1	NOM (e.g. humic acid) addition	difference in toxicity	(dependent on toxicity assay)	ion	[1, 2]
		2	Insoluble salt-forming agent addition, including orthophosphate, sulfide, sodium thiosulfate, sodium chloride	difference in toxicity	(dependent on toxicity assay)	ion, contact	[2-5]
		3	Chelator addition, including NAC, EDTA, bathocuproine, neocuproine	difference in toxicity	(dependent on toxicity assay)	ion, contact	[3, 6-14]
		4	Use NP concentration below toxic ion release threshold	difference in toxicity	(dependent on toxicity assay)	ROS	[15]
	2	5	Compare colloidal to immobilized NPs	difference in toxicity	(dependent on toxicity assay)	ion, contact, internalization	[2, 16-18]
		6	Compare to NP-free filtrate	difference in toxicity	(dependent on toxicity assay)	ion, contact	[1, 4, 19-27]
		7	Membrane barrier	difference in toxicity	(dependent on toxicity assay)	ion, contact	[28-30]
		8	Induce aggregation, including extracellular polymeric substance (EPS) addition	difference in toxicity	(dependent on toxicity assay)	ion, contact	[1, 30-32]
		9	Compare to inert NPs of same size and morphology	difference in toxicity	(dependent on toxicity assay)	contact	[33-37]
		10	Compare toxicity in aerobic and anaerobic environment	difference in toxicity	(dependent on toxicity assay)	ion, contact, ROS	[3, 38, 39]
	3	11	Cysteine (e.g. NAC) addition	difference in toxicity	(dependent on toxicity assay)	ROS	[21, 24, 35, 39-43]
		12	Ascorbic acid addition	difference in toxicity	(dependent on toxicity assay)	ROS	[41, 44, 45]
		13	Methanol addition	difference in toxicity	(dependent on toxicity assay)	ROS	[46, 47]
		14	Vitamin E addition	difference in toxicity	(dependent on toxicity assay)	ROS	[28]
		15	Mannitol addition	difference in toxicity	(dependent on toxicity assay)	ROS	[28]
		16	GSH addition	difference in toxicity	(dependent on toxicity assay)	ROS	[5, 28, 44]
		17	SOD addition	difference in toxicity	(dependent on toxicity assay)	ROS	[10, 24, 43, 46]
		18	CAT addition	difference in toxicity	(dependent on toxicity assay)	ROS	[10, 43, 48, 49]
		19	DMSO addition	difference in toxicity	(dependent on toxicity assay)	ROS	[43]

		20	t-butanol addition	difference in toxicity	(dependent on toxicity assay)	ROS	[48]
		21	Ammonium oxalate addition	difference in toxicity	(dependent on toxicity assay)	ROS	[48]
		22	BQ addition	difference in toxicity	(dependent on toxicity assay)	ROS	[48, 50]
		23	p-benzoic acid addition	difference in toxicity	(dependent on toxicity assay)	ROS	[51]
		24	IPA addition	difference in toxicity	(dependent on toxicity assay)	ROS	[50]
		25	EDTA-Fe	difference in toxicity	(dependent on toxicity assay)	ROS	[52]
		26	TEMPOL	difference in toxicity	(dependent on toxicity assay)	ROS	[52]
	4	27	NP pre-irradiation	difference in toxicity	(dependent on toxicity assay)	photoactivity	[53-56]
		28	Compare toxicity in light vs dark conditions	difference in toxicity	(dependent on toxicity assay)	photoactivity	[13, 46, 57-81]
	5	29	Add osmotic support	difference in toxicity	(dependent on toxicity assay)	membrane	[82]
	6	30	Soluble salt (e.g. AgNO3, CuSO4, ZnCl2)	difference in toxicity	(dependent on toxicity assay)	ion, contact	[6-8, 13, 20, 22, 28-31, 34-36, 52, 54, 55, 59-61, 71, 77, 83-130]
		31	Metal plate	difference in toxicity	(dependent on toxicity assay)	ion, contact	[2, 16]
		32	H2O2	difference in toxicity	(dependent on toxicity assay)	ROS	[13, 21, 30, 125]
		33	Detergent/bacteriolytic agent	difference in toxicity	(dependent on toxicity assay)	membrane	[97, 131-133]
2	7	34	Recombinent bioluminescent reporter strain	various (incl. intracellular ROS species, bioavailable metal, DNA damage, membrane damage)	chemiluminometric	ion, ROS, membrane, DNA, protein	[7, 10, 27, 40, 72, 83, 90, 93, 94, 115, 124, 134-137]
		35	Single-gene deletion ("knockout") strain	difference in toxicity	(dependent on toxicity assay)	ion, ROS, DNA	[93, 115, 137, 138]
	8	36	Transcriptome analysis	quantity of RNA produced relative to control (indicates up- and down-regulation of relevant genes)	various, usually microarray or high-throughput sequencing	ion, contact, ROS, membrane, DNA, protein	[21, 26, 36, 40, 72, 75, 99, 118, 123, 138-151]

		37	Proteome analysis	quantity of protein produced relative to control (indicates up- and down-regulation of relevant genes)	various, usually mass spectrometry	ion, contact, ROS, membrane, DNA, protein	[11, 44, 71, 97, 101, 104, 128, 145, 147, 148, 152-155]
	9	38	NBT assay	Usually superoxide anion levels; inhibition of stain is also used as a measure for SOD activity	colorimetric	protein	[156]
		39	Ammonium molybdate assay	CAT activity	colorimetric	ROS, protein	[6, 11, 24, 44, 133, 156]
		40	NADPH/NaN3 assay	GPX activity	colorimetric	ROS	[11]
		41	CDNB/GSH assay	GST activity	colorimetric	ROS, protein	[11, 156]
		42	Peroxidase activity assays, including pyrogallol and guaiacol	Peroxidase activity	colorimetric or fluorometric	ROS	[44, 157]
		43	DTNB assay	GR activity	colorimetric	ROS, protein	[13, 24, 158]
		44	NADH assay (with INT or resorufin)	Dehydrogenase activity	colorimetric or fluorometric	protein, ROS	[11, 107, 117, 126, 152, 156, 158-161]
		45	Lipase activity (Randox)	Lipase activity	colorimetric	protein	[107, 156]
		46	ONPG assay	GAL activity	colorimetric	protein	[52, 162]
		47	Phenol red urease assay	Urease activity	colorimetric	protein	[163]
		48	Acetylene reduction assay	Nitrogenase activity	GC	protein	[151]
		49	P-NPP assay	Alkaline phosphatase activity	colorimetric	protein	[14]
3	10	50	XAS analysis of metal in cell mass or supernatant	Local geometric and electronic structure of metal atoms	EXAFS and/or XANES	ion, contact, internalization, ROS	[91, 164-167]
		51	XPS analysis of NP/cell interface	Oxidation state of metal	XPS	photoactivity, contact, ROS	[63, 73]
		52	Speciation modeling	Metal speciation in supernatant	in silico	ion, contact	[167]
	11	53	FTIR of cellular fraction or extracellular polymeric substances (EPS)	Chemical changes in cellular components	FTIR	contact, membrane, protein, DNA	[47, 48, 63, 71, 82, 84, 116, 166, 168-174]
		54	Raman spectroscopy of cellular fraction	Chemical changes in cellular components	Raman spectroscopy	protein, DNA	[25, 63, 175]
		55	Peptidoglycan analysis	Chemical changes in cell wall components	GC/MS and CD spectroscopy	membrane	[176]

		56	TBA/MDA assay	Degree of lipid peroxidation	colorimetric or fluorometric	ROS, membrane	[5, 21, 24, 43, 52, 58, 66, 83, 111, 156, 172, 177-186]
		57	DNPH assay	Protein carbonyl content (indicates protein oxidation)	colorimetric	ROS	[155, 177]
		58	RNA degradation assay	Changes in RNA lengths relative to control	gel electrophoresis	protein	[187]
		59	AOPP assay	AOPP formation (indicates protein oxidation)	UV-Vis	protein, ROS	[182, 188]
4	12	60	Reversability study (i.e. recovery of cell growth after removal of NPs from system) for cell-associated metal	Growth rate relative to control	(dependent on toxicity assay)	ion, contact	[122]
		61	Metal concentration in cellular fraction, including sucrose gradient centrifugation assay	Quantity of metal associated with cells	ICP-MS	ion, contact, internalization	[96, 98, 128, 151, 164, 189-192]
		62	Metal concentration in cell-free filtrate	Quantity of metal remaining in suspension	ICP-MS	contact, internalization	[193]
		63	NPs suspended in supernatant	Quantity of colloidal metal removed from suspension compared to pre-cell exposure	UV-Vis	contact	[29]
	13	64	SEM	Qualitative attributes of cell/NP interaction	Image of cell exterior	contact, membrane	[5, 25, 30, 32, 42, 43, 48, 50, 62, 70, 82, 107, 113, 129, 151, 161, 181, 183, 184, 187, 193-223]
		65	SEM with elemental mapping (EDX or synchrotron XFM)	Qualitative attributes of cell/NP interaction	Image of cell exterior with elemental mapping	contact, membrane	[126, 127, 171, 224-228]
		66	AFM	Qualitative attributes of cell/NP interaction	Image of cell surface	contact, membrane	[14, 17, 130, 136, 170, 173, 197, 229-231]

	14	67	TEM	Qualitative attributes of cell/NP interaction	Image of cell interior	membrane, contact, internalization, DNA	[12, 30, 44, 52, 61, 64, 68, 84, 93, 113, 119, 129, 132, 141, 150-152, 161, 165, 168, 172, 176, 184, 212, 232-248]
		68	TEM with elemental mapping (EDX or synchrotron XFM)	Qualitative attributes of cell/NP interaction	Image of cell interior with elemental mapping	contact, internalization, membrane	[10, 19, 47, 83, 96, 100, 104, 150, 171, 179, 224, 226, 227, 249-253]
	15	69	CLSM	Qualitative attributes of cell/NP interaction (for intrinsically fluorescent NPs)	fluorescence microscopy	contact, internalization, membrane, DNA	[80, 237, 254-257]
		70	Two-photon microscopy with ion-specific label	Relative quantity of free ions within cells	fluorescence microscopy	ion, contact, internalization	[96]
		71	DLE with PI stain	Association between NPs and dead cells (for NPs with DLE, e.g., ZnO)	fluorescence microscopy	contact	[96]
		72	Dark-field microscopy (may be equipped with HSI)	Relative strength of interactions between NPs and cell surfaces	light microscopy	contact, membrane	[96, 99, 192, 258]
		73	Fluorescence microscopy with protein labeling	Localization of target proteins within cells	fluorescence microscopy	contact	[105, 192]
		74	NP tracking with intrinsic fluorescence or fluorescent label (e.g. rhodamine B)	Localization of NPs within cells	fluorescence microscopy	contact, internalization	[105, 155, 206]
		75	Light scattering method for particle internalization	Ratio of forward- to side-scattered light (varies with cell granularity)	light microscopy	internalization	[13, 201, 241, 259]
5	16	76	ONPG hydrolysis assay	GAL leakage	colorimetric	membrane	[45, 155, 169, 184, 195, 208, 260]
		77	K+ and/or Mg2+ leakage	K+ and/or Mg+ in supernatant	AAS/AES or selective electrode	membrane	[28, 106, 122, 129, 145, 168, 184, 218, 245]
		78	Tetraphenylborate assay	K+ in supernatant	colorimetric	membrane	[48]
		79	TPP+ leakage	TPP+ in supernatant	selective electrode	membrane	[106]

		80	Nucleic acid leakage	Nucleic acids in supernatant	UV-Vis	membrane	[9, 43, 45, 98, 133, 155, 169, 194, 205, 211, 225, 240, 255, 261-263]
		81	Sodium pyruvate assay	LDH in supernatant	UV-Vis	membrane	[87, 104, 171, 174, 179, 191, 256, 264-266]
		82	Lowry method	Protein in supernatant	colorimetric	membrane	[45, 159, 201, 257, 260]
		83	Bradford method	Protein in supernatant	colorimetric	membrane	[48, 50, 117, 133, 156, 160, 161, 169, 214, 218, 228, 242, 262, 264, 267-269]
		84	Miller method	Reducing sugar in supernatant	colorimetric	membrane	[117, 126, 156, 159, 160, 242, 262, 267-269]
		85	DNA release, including diphenylamine and PicoGreen assays	DNA in supernatant	fluorometric	membrane	[9, 32, 98, 217, 258]
		86	RNA gel electrophoresis	RNA in supernatant	gel electrophoresis	membrane	[184]
		87	P-NPP assay	Alkaline phosphatase in supernatant	colorimetric	membrane	[14, 130, 264]
		88	EMA qPCR assay	DNA in cells with compromised membranes	gel electrophoresis	membrane	[204]
	17	89	DNA ladder assay	Degree of gDNA fragmentation	gel electrophoresis	DNA, protein	[45, 52, 107, 163, 165, 177-180, 215, 218, 265, 270]
		90	UV-Vis assay	Degree of gDNA fragmentation	spectrophotometric	DNA	[188, 237]
		91	HPLC	Degree of DNA oxidation	HPLC	DNA	[182, 188]
		92	Viscosity assay	Viscosity of DNA solution (as a metric for mode of interaction with NPs)	rotational viscometer	DNA	[178]
	18	93	DCFH-DA (including variants such as CM-H2DCFDA, ab113851-DCFDA, H2DCFDA, DCF-DA)	Intracellular ROS	fluorometric	ROS	[5, 21, 22, 24, 32, 39, 42-44, 62, 64, 67-69, 75-77, 83, 87, 88, 96, 120, 128, 132, 142, 149, 151, 156, 157, 159, 171-174, 177, 179-183, 186, 187, 189, 190, 192, 194-196, 201, 206, 207, 211, 212, 216, 225, 239, 241, 252, 256, 257, 259, 265, 271-275]

		94	NBT assay	Usually superoxide anion levels; inhibition of stain is also used as a measure for SOD activity	colorimetric	ROS	[11, 24, 44, 46, 54, 98, 157, 171, 174, 178, 225, 256, 262, 276]
		95	Rhodamine dyes, including DHR6G and dihydrorhodamine 123	Intracellular ROS	fluorometric	ROS	[82, 181, 277, 278]
		96	Hydroxylamine assay (cells must be lysed)	Intracellular O2-	fluorometric	ROS	[44]
		97	Propidium iodide (PI) stain	Membrane permeability (enters cells with compromised membranes)	fluorometric	membrane	[9, 12, 20, 22, 32, 43, 47, 63, 68, 77, 87, 91, 96, 108, 113, 114, 126, 129, 138, 151, 165, 166, 171, 173, 183, 187, 189, 196, 199, 205, 212, 216, 225, 241, 263, 270, 273, 274, 279, 280]
		98	Ethidium bromide (EtBr) stain	Membrane permeability (enters cells with compromised membranes and stains DNA)	fluorometric	membrane	[174]
		99	DiBAC4 stain	Membrane potential	fluorometric	membrane	[114, 126, 149]
		100	diSC3(5) assay for membrane potential	Membrane potential	fluorometric	membrane	[52, 97, 201, 209, 258]
		101	1-NPN	Outer membrane permeability	fluorometric	membrane	[9, 106, 155, 183, 194, 211]
		102	DPH membrane fluidity assay	Membrane fluidity	fluorometric	membrane	[132, 201, 218, 273]
		103	ANS probe	Membrane potential	fluorometric	membrane	[188]
		104	TUNEL assay	Degree of apoptosis	fluorometric	DNA	[149, 201, 216]
		105	DAPI stain	Stains DNA	fluorometric	internalization	[179, 201]
		106	Hoechst 33342	Stains DNA	fluorometric	internalization	[189]
		107	Annexin V	Degree of apoptosis	fluorometric	protein	[44, 149, 281]
		108	CaspACE FITC-VAD-FMK stain	Intracellular caspase-like protein (as a marker for apoptosis)	fluorometric	protein	[149]
		109	RedoxSensor assay	Reductase activity	fluorometric	ROS	[91, 165, 166]

	19	110	DTNB assay for cellular GSH	Quantity of disulfide-containing molecules	colorimetric	ROS, protein	[13, 156, 173, 179, 181]
		111	8-oxoguanine assay for oxidative DNA damage	Oxidative damage	LC-MS/MS	DNA	[5]
		112	Dissolved oxygen	Cell respiration	colorimetric	membrane, protein	[106]
		113	MTT	Cell respiration	colorimetric	protein	[158]
		114	TTC reduction	Dehydrogenase activity	colorimetric	protein	[66, 191]
		115	Luciferin/trichloroacetic (TCA) assay for ATP content	Cell respiration	chemiluminometric	protein	[1, 43, 52, 83, 97, 126, 156, 218, 238]
		116	AMO- and HAO-specific SOUR measurements	Cell respiration (following blockage of one or multiple SOUR-relevant enzymes)	SOUR	protein	[122]
		117	NAD+/NADH ratio	Cell respiration	colorimetric	protein	[5]
		118	Intracellular K+ or Ca2+	Cell respiration (as a reflection of membrane damage and metabolic disruption)	flame AES	protein	[52, 97, 149]
		119	EPS quantification	EPS production (as a measure of cell viability or metabolic activity)	colorimetric	protein	[166, 191, 225]
		120	OmpA immunoblot	Accumulation of precursor forms of membrane proteins	immunoblot	protein	[97]
		121	Phag-GFP expression assay	Degree of Phag-GFP expression relative to control	chemiluminometric	protein	[165, 166, 282]
		122	X-gal plating assay	Portion of population expressing beta-galactosidase relative to control	colony color	DNA	[197]
		123	SDS-PAGE for general protein damage	Changes in protein masses compared to control	gel electrophoresis	protein	[108]
	20	124	EPR/ESR	Quantity of ROS (species depends on spin trap used)	ESR	ROS	[46, 67, 71, 78, 83, 99, 148, 151, 172, 205, 216, 275, 283, 284]

	21	125	Ames test	Number of mutations caused by material	number of colonies	DNA	[194, 211, 285-287]
	22	126	EtBr cartwheel efflux pump inhibition assay	Eliminates ion efflux inhibition	Role of intracellular ions in toxicity and corresponding cellular defense mechanisms	ions, internalization	[9]
6	23	127	NP-protein interaction modeling	Number and type of possible interactions between NPs and target proteins	in silico	contact, protein, membrane	[288]
		128	NP/peptidoglycan interaction modeling	Theoretical affinity of NPs for peptidoglycan	in silico	contact	[253]
		129	in vitro analysis of fatty acids on NP thin film	Chemical and structural changes in fatty acids (key components of plasma membrane)	XPS	membrane	[70]
		130	in vitro peptidoglycan assay	Chemical changes in peptidoglycan (key component of cell wall)	UV-Vis	protein	[258]
		131	in vitro resorufin β-D-galactopyranoside assay	NP inhibition of GAL in vitro	fluorometric	protein	[162]
		132	in vitro enzyme activity assay	NP inhibition of enzyme activity in vitro	various, usually colorimetric	protein	[52, 87, 104]
		133	In vitro disulfide bond interaction assay	Amount of insulin bound to NPs	gel electrophoresis	protein	[107]
		134	In vitro protein binding assay	Amount of GAL binding to NPs	gel electrophoresis	protein	[162]
		135	In vitro protein binding assay	Amount of BSA bound to NPs	UV-Vis	protein	[260]
	24	136	in vitro DNA fragmentation assay	Degree of plasmid fragmentation	gel electrophoresis	DNA	[178, 189, 267]
		137	in vitro DNA interaction assay	Amount of DNA bound to NPs	UV-Vis	DNA	[177]
	25	139	pyranine lipid vesicle assay	Degree of synthetic membrane permeability	pH change	contact	[30, 49]
		140	liposome carboxyfluorescein assay	Degree of synthetic membrane permeability	fluorometric	membrane	[28, 231]

		141	Synthetic membrane surface pressure assay	Surface pressure on membrane (as a measure of mechanical stress created by NPs)	DLS	membrane	[289]
		142	Three-electrode assay with synthetic (e.g. DOPC) membrane	Electrostatic attraction between NPs and synthetic membrane	three-electrode system	contact	[219]
		143	in vitro TBA/MDA assay	Degree of lipid peroxidation in vitro	colorimetric or fluorometric	ROS	[55, 111]
	26	144	e.g. fumarase A and sulfite reductase			protein	[98]
7	27	145	ICP-MS, -OES, -AES	Concentration of ions in exposure media	ICP-MS, -OES, -AES	ion	[6, 8, 11-16, 19, 20, 34, 36, 38, 42, 43, 51, 58, 60, 61, 64, 71, 72, 77, 79, 82, 84, 94-97, 99, 101, 103, 108, 110-112, 114, 115, 120-122, 125, 127, 128, 130, 132, 142, 157, 164, 172-174, 178, 189, 193, 210, 216, 217, 226, 250, 252, 259, 261, 278, 279, 283, 284, 290-301]
		146	AAS	Concentration of ions in exposure media	AAS	ion	[10, 27, 29, 32, 46, 48, 54, 91, 113, 116, 124, 135, 138, 191, 199, 200, 205, 266, 302, 303]
		147	HPLC		HPLC	ion	[23]
		148	ASV	Concentration of ions in exposure media		ion	[304]
		149	chloride precipitation	Concentration of ions in exposure media	colorimetric	ion	[41]
		150	silver/sulfide electrode	Concentration of ions in exposure media	selective electrode	ion	[29, 43, 88, 277, 282]
		151	Alizarin red S (ARS)	Concentration of ions in exposure media	colorimetric	ion	[9]

	28	152	GSH oxidation (DTNB)	ROS quantity	colorimetric	ROS, protein	[19, 58, 174, 199, 207, 300]
		153	XTT	Superoxide quantity	colorimetric	ROS	[59-61, 79, 187, 194, 199, 211, 300, 305]
		154	HE (hydroethidene)	Superoxide quantity		ROS	[172]
		155	Methyl orange	ROS quantity		photoactivity, ROS	[172, 294, 295]
		156	Methylene blue	ROS quantity		photoactivity, ROS	[53, 68, 69, 146, 261, 306]
		157	3'-(p-aminophenyl) fluorescein (APF)	Hydroxyl quantity		ROS	[21, 88, 146]
		158	3-(p-hydroxyphenyl) fluorescein (HPF)			photoactivity, ROS	[47, 172]
		159	Rhodamine B			ROS	[244]
		160	KI UV-Vis assay for H2O2	H2O2 quantity	colorimetric	ROS	[278]
		161	DMSO H2O2 colorimetric assay	H2O2 quantity	colorimetric	ROS	[302]
		162	HRP horseradish peroxide assay	H2O2 quantity		ROS	[28]
		163	KMnO4 redox titration			ROS	[46, 276]
		164	DCPIP			photoactivity, ROS	[72]
		165	DPPH			ROS	[228]
		166	Terepthalic acid (or Phth)	Hydroxyl quantity		ROS	[15, 46, 50, 276]
		167	Luminol for superoxide	Superoxide quantity	chemiluminometric	ROS	[15, 83]
		168	Luminol+ferricyanide for H2O2	H2O2 quantity	chemiluminometric	ROS	[15]
		169	p-chlorobenzoic acid (pCBA)			ROS	[51, 59-61, 79]
		170	FFA			ROS	[59-61, 79]
		171	Amplex Red	H2O2 quantity	colorimetric	ROS	[49]
		172	Singlet Oxygen Sensor Green (SOSG)	Singlet oxygen quantity	fluorometric	ROS	[172]
		173	Pentafluorobenzenesulfonyl fluorescein (PFBSF)		fluorometric	ROS	[172]
		174	Deoxyribose			ROS	[98]
	29	175	Electrical impedence (for film-embedded NPs)	difference in toxicity	(dependent on toxicity assay)	contact	[307]
		176	Defect sites or oxygen vacancies (measured by PL spectroscopy or XPS)	difference in toxicity	(dependent on toxicity assay)	ROS	[146, 276, 299, 308-311]
		177	Morphology	difference in toxicity	(dependent on toxicity assay)	ions, contact	[270, 293, 300, 306, 312-315]

		178	Zeta potential	difference in toxicity	(dependent on toxicity assay)	contact, membrane	[14, 41, 65, 95, 130, 135, 136, 171, 173, 174, 190, 252, 295]
		179	Surface coating	difference in toxicity	(dependent on toxicity assay)	ion, contact	[33, 89, 170, 316, 317]
		180	Interaction energy (calculated based on EDLVO theory)	difference in toxicity	(dependent on toxicity assay)	ROS	[276]
	30	181	model organism Gram type	difference in toxicity	(dependent on toxicity assay)	contact	[62, 221, 309]

Table S4. List of abbreviations and acronyms used in Table 3 and Table S3

AOPP	Advanced oxidation protein products
CAT	catalase
CD	Circular dichroism
CDNB	1-chloro-2,4-dinitrobenzene
CLSM	confocal laser scanning microscopy
DAPI	4′,6-diamidino-2-phenylindole
DCFH-DA	2′,7′-Dichlorofluorescin Diacetate
DiBAC4(3)	Bis-(1,3-Dibutylbarbituric Acid)Trimethine Oxonol
DiSC3(5)	3,3’-diphenylthiocarbocyanine iodide
DLE	deep level emission
DMSO	dimethyl sulfoxide
DNPH	2,4-dinitrophenylhydrazine
DPH	Diphenylhexyltriene
DTNB	5,5'-dithiobis-(2-nitrobenzoic acid)
EDTA	Ethylenediaminetetraacetic acid
EMA	ethidium monoazide
EPR	electron paramagnetic resonance spectroscopy
EPS	extracellular polymeric substance
ESR	electron spin resonance spectroscopy
FFA	fufuryl alcohol
GAL	Beta-galactosidase
GC	gas chromatography
GFP	green fluorescent protein
GPX	Glutathione peroxidase
GR	glutathione reductase
GSH	glutathione
GST	glutathione-s-transferase
H-NS	histone-like nucleoid structuring proteins
INT	Iodonitrotetrazolium
IPA	isopropanol
LDH	lactate dehydrogenase
MDA	Malondialdehyde
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
Na2S2O3	sodium thiosulfate
NAC	N-acetyl L-cysteine
NaCl	sodium chloride
NADH	1,4-Dihydronicotinamide adenine dinucleotide
NADPH	beta-Nicotinamide Adenine Dinucleotide Phosphate, Reduced
NBT	Nitro blue tetrazolium

NOM	natural organic matter
ONPG	o-nitrophenyl-beta-D-galactopyranoside
P-NPP	para-nitrophenol phosphate
Pyranine	8-hydroxy-1,3,6-pyrene-trisulfonate
qPCR	quantitative polymerase chain reaction
SDS-PAGE	sodium dodecyl sulfate polyacrylamide gel electrophoresis
SOD	superoxide dismutase
SOUR	specific oxygen uptake rate
TBA	Thiobarbituric acid
TEMPOL	4-Hydroxy-TEMPO or 4-hydroxy-2,2,6,6-tetramethylpiperidin-1-oxyl
TPP	tetraphenylphosphonium
TTC	2,3,5-triphenyltetrazoilum chloride
TUNEL	terminal deoxynucleotidyl transferase dUTP nick end labeling
XAS	X-ray absorption spectroscopy, including XANES (X-ray absorption near edge structure) and/or EXAFS (extended X-ray absorption fine structure)
XTT	2,3-Bis-(2-Methoxy-4-Nitro-5-Sulfophenyl)-2H-Tetrazolium-5-Carboxanilide

Table S5. Summary of advantages and limitations of specific method Groups, Approaches, and Techniques that have been proposed in the literature. When advantages and limitations were reported for multiple sets of methods containing a particular Technique, this Technique is listed multiple times. For definitions of specific Groups, Approaches, and Techniques, see Table 4 in the main text.

Group	Approach	Technique	Documented Advantages and/or Limitations
1	2	10	Dissolution may occur through non-oxidative means, so anaerobic conditions may not eliminate antibacterial activity from dissolved ions [318].
	3	12, 16	Enzymes that utilize GSH and ascorbate are not present in certain bacterial species including E. coli, so these compounds are not useful as “diagnostic antioxidants” [319].
	6	30	The kinetics of ion leaching from ENMs are not captured in pulse ion addition [99]. Exposure media: certain ligands may generate misleading results by preferentially decreasing the bioavailability and antibacterial activity of dissolved ions [3]. Dose of soluble salt: must deliver the dose that the bacteria actually receive on ENM exposure in the relevant study conditions, rather than simply matching the mass of salt to the mass of ENMs [318]. If salt dosing is based on ion leaching experiments, the conditions of these assays may also affect results (see Group 7). Antibacterial activity of the counter-ion in soluble salt experiments [28]: can be mitigated by removing the anion from the system or controlling for its toxic effect.
2	7	34	Recommended as a screening step for multiple mechanisms due to their relative simplicity [320]. Metal-sensing biosensors may be the most accurate way to assess the “true bioavailable content” [321]. Biosensors are not as precise as analytical methods for assessing cell-associated metal, and the “bioavailable” fraction excludes complexes which have been shown to exert toxic effects in bacteria [115].
	8	36, 37	Ability to detect “broad coordinated trends” [322], particularly useful for providing more detailed resolution of "cell effects" aspects of antibacterial activity mechanism (e.g., membrane and DNA damage) [104, 124]. High-throughput methods are reliant on precise and accurate understanding of the function of genes in the model organism, including reference genes whose expression is not expected to change during the study [36]. Since a complete picture of gene function and bacteria physiology is not straightforward to achieve, misinterpretations may lead to erroneous conclusions, similar to those revealed about the role of ROS in the action of several antibiotics [319]. Transcriptome analysis may require the establishment of a “normal” or “background” cell phenotype, which can vary between studies [323]. Protein expression varies depending on stage of cell cycle, which introduces added variability into proteome analysis results [323].

3	(All Group 3)		Ability to connect the binary presence or absence of a mechanistic phenomenon to either its origin (i.e. ions or particles) or the chemical changes responsible. Most Group 3 methods are readily conducted at multiple time points to study the kinetics of cellular degradation [324].
	10	50	XPS and XAS of cellular metal can help establish whether intracellular metal represented in-tact ENMs or re-oxidized ions [91, 165, 166] .
	11	53	FTIR promoted as a means to show specific chemical changes that take place during membrane and protein damage [324].
4	12	61	Metal partitioning studies are the only quantitative means to assess cell-associated metal, but contain no information about ENM localization or whether the metal in question represents particles or dissolved ions [325].
	13, 14	64, 65, 67, 68	Protocols to minimize TEM and SEM artefacts are outlined in [326]. Potential for artefacts with TEM and SEM [327], including dark spots from osmium tetroxide residue that may be mistaken for ENMs [16, 326], as well as less readily identifiable artefacts that arise from the reaction of ENMs with fixation or staining agents [326]. TEM is known to induce "slight membrane damage" during sample preparation [166]. Lack of z-resolution in TEM may make it unsuitable for studying internalization [36]. ENMs may detach from membranes during sample preparation, generating false negatives in investigations of contact-mediated antibacterial activity mechanisms [96].
	14	66	AFM is adept at detailed study of cell surfaces and their mechanical properties [324], for example, through calculation of surface roughness and force-distance curves and the use of chemical force mapping [328]. Some have touted AFM as a means to move beyond simple binary designations of cell-ENM interactions (e.g., “morphology change” and “membrane damage”) and towards a more complex understanding of the mechanical changes that occur in the cell as a result of ENM exposure [329].
	15	(All Approach 15)	High-throughput assays using fluorescence or light-scattering involve no fixation procedure and may help discern between ENM internalization and adsorption to the outer cell surface at the “bulk” level [325, 330]. These methods also enable the correlation of internalization rate with antibacterial activity in order to establish whether NP internalization is actually important [96, 259]. Lower resolution of high-throughput methods leave them powerless to discern ENM localization in detail, and they must be coupled with ICP-MS or other analytical method to provide quantitative information [325]. Light-scattering methods were adapted from eukaryotic cells and are comparatively less well-tested in prokaryotes [13].

5	(All Group 5)		The majority of methods are fluorescent probes which, while commonly used, are not recommended as the sole means of gauging ROS accumulation; ESR/EPR (Approach 20, Technique 134) has been proposed as an alternative [331].
	16	81	Purportedly not suitable for ENMs that bind proteins or produce ROS [332], which potentially includes all the ENM classes reviewed here, since they may inhibit the enzymatic conversion by LDH. Further ambiguities are created if the material absorbs at the necessary wavelength, which may include nAg [333].
	18	(All Approach 18)	Intracellular probes may penetrate cells to differing degrees depending on membrane permeability [132], may be actively excreted by bacterial pmf-dependent pumps [319], and may artificially appear to fluoresce more due to the morphological changes that take place in bacteria under stress [319].
		93	DCFH-DA may be subject to autocatalytic degradation [323], and different preparation protocols have been shown to yield different results depending on the time at which the probe is added, the incubation time, and the predominant species [334].
		93, 94, 95	Dyes which operate via a radical intermediate, including fluorescein and rhodamine dyes, NBT, and lucigenin, may be sensitive to redox-cycling mechanisms in the presence of oxygen that artificially amplify the fluorescence signal [319, 331, 335].
		97, 105, 106	The PI, DAPI, and Hoechst stains are subject to background signal from ENMs with red or blue fluorescence [333].
	21	125	The Ames reverse mutation test, a staple of the genotoxicity testing toolkit, is shown by multiple sources to be inappropriate for studies of DNA damage in ENMs due to its tendency to cause premature negative conclusions. Reasoning ranges from the high antibacterial activity of ENMs and their tendency to cause large-scale chromosomal damage as opposed to point mutations [194, 336] to the potentially limited uptake of ENMs into the cytoplasm [337] and the aggregation and lack of electrostatic attraction between ENMs and bacteria in the standard test medium [287].
7	27	(All Approach 27)	For ion release studies, the extent of dissolution depends heavily on media composition [23, 338, 339] and presence or absence of cells [115, 339]. Important variables to control for in exposure media include pH, ionic strength, NOM, and oxygen content [340]. Dissolution often takes place at the nano-bio interface, and specific proteins found in bacteria have been found to mediate oxidative dissolution while others do not, an example of complex dissolution processes which are not captured in acellular dissolution assays [341]. Measuring the concentration of dissolved ions does not account for the fraction of ions that are bioavailable, nor does it establish conclusively that the ions actually contribute to antibacterial activity [342].

	28	(All Approach 28)	Extracellular ROS measurements were found to be affected by pyruvate, a common ingredient in cell media that acts as an ROS scavenger [343]. Tetrazolium derivatives may be adsorbed to ENMs and lose activity [333].

Table S6. Mean and standard deviation of bootstrapped Consistency Scores, disaggregated by core composition. The number of studies in each set is also listed in the "n" columns.

Question	Group	Approach	Technique	Ag			Cu			CuO			TiO2			ZnO		
				Median	StDev	n	Median	StDev	n	Median	StDev	n	Median	StDev	n	Median	StDev	n
Ion	(all)			0.143	0.050	55	0.163	0.117	9	0.122	0.078	19	0.500	0.000	0	0.055	0.037	31
	1			0.107	0.062	27	0.280	0.171	3	0.100	0.072	12	0.500	0.000	0	0.078	0.052	14
	1	1		0.168	0.120	5	0.500	0.000	2	0.500	0.000	2	0.000	0.000	0	0.500	0.000	1
	1	1	3	0.275	0.179	3	0.000	0.000	0	0.186	0.161	2	0.000	0.000	0	0.208	0.154	2
	1	2		0.218	0.124	6	0.000	0.000	0	0.223	0.151	2	0.000	0.000	0	0.229	0.143	2
	1	2	6	0.132	0.070	21	0.262	0.251	1	0.146	0.097	12	0.500	0.000	0	0.074	0.061	12
	1	6		0.107	0.070	21	0.243	0.251	1	0.167	0.084	12	0.500	0.000	0	0.083	0.056	12
	1	6	30	0.128	0.069	21	0.213	0.248	1	0.155	0.103	12	0.500	0.000	0	0.083	0.057	12
	2			0.313	0.113	9	0.500	0.000	0	0.500	0.000	2	0.500	0.000	0	0.173	0.116	3
	2	7		0.386	0.109	7	0.000	0.000	0	0.500	0.000	2	0.500	0.000	0	0.270	0.179	3
	2	7	34	0.357	0.125	6	0.000	0.000	0	0.500	0.000	2	0.500	0.000	0	0.270	0.186	3
	4			0.358	0.166	2	0.266	0.153	2	0.299	0.164	1	0.000	0.000	0	0.500	0.000	0
	4	12		0.342	0.167	2	0.269	0.155	2	0.279	0.158	1	0.000	0.000	0	0.500	0.000	0
	7			0.146	0.066	34	0.190	0.116	6	0.186	0.108	10	0.500	0.000	0	0.081	0.065	24
	7	27		0.131	0.069	33	0.197	0.124	6	0.167	0.097	10	0.500	0.000	0	0.089	0.057	24
	7	27	145	0.131	0.079	23	0.292	0.181	1	0.214	0.113	9	0.500	0.000	0	0.117	0.072	20
	7	27	146	0.260	0.132	6	0.500	0.000	4	0.238	0.251	1	0.000	0.000	0	0.156	0.126	3
Particle	(all)			0.338	0.043	71	0.333	0.091	14	0.317	0.090	18	0.392	0.074	17	0.332	0.053	41
	1			0.288	0.067	22	0.292	0.162	2	0.258	0.127	9	0.000	0.000	0	0.243	0.128	8
	1	2		0.350	0.101	10	0.000	0.000	0	0.314	0.153	4	0.500	0.000	0	0.500	0.000	0
	1	6		0.323	0.069	17	0.500	0.000	2	0.211	0.122	6	0.000	0.000	0	0.285	0.119	8
	1	6	30	0.303	0.086	16	0.500	0.000	2	0.194	0.116	6	0.000	0.000	0	0.287	0.128	8
	3			0.260	0.187	3	0.000	0.000	0	0.500	0.000	0	0.500	0.000	4	0.500	0.000	3
	4			0.385	0.047	44	0.324	0.112	9	0.500	0.000	13	0.376	0.075	14	0.368	0.072	20
	4	12		0.275	0.185	3	0.272	0.156	2	0.500	0.000	2	0.500	0.000	1	0.500	0.000	1

	4	**13**		0.452	0.054	19	0.500	0.000	3	0.500	0.000	6	0.347	0.131	6	0.362	0.092	13
	4	**13**	**64**	0.500	0.000	11	0.500	0.000	2	0.500	0.000	5	0.337	0.149	5	0.344	0.110	10
	4	**14**		0.359	0.059	30	0.318	0.150	4	0.500	0.000	5	0.392	0.116	7	0.402	0.084	9
	4	**14**	**67**	0.369	0.061	24	0.500	0.000	3	0.500	0.000	2	0.500	0.000	5	0.338	0.142	5
	4	**14**	**68**	0.361	0.125	6	0.243	0.251	1	0.500	0.000	3	0.276	0.157	2	0.500	0.000	4
	7			0.373	0.121	7	0.500	0.000	2	0.500	0.000	1	0.500	0.000	2	0.314	0.155	5
	7	**29**		0.378	0.125	6	0.500	0.000	2	0.500	0.000	1	0.500	0.000	2	0.314	0.145	4
	7	**29**	**178**	0.292	0.187	3	0.500	0.000	1	0.500	0.000	1	0.500	0.000	2	0.500	0.000	2
Internalization	**(all)**			0.273	0.061	35	0.393	0.104	8	0.166	0.105	5	0.500	0.000	7	0.198	0.096	14
	4			0.237	0.080	23	0.500	0.000	6	0.290	0.153	4	0.500	0.000	6	0.246	0.119	8
	4	**14**		0.189	0.096	15	0.500	0.000	3	0.285	0.173	3	0.500	0.000	6	0.286	0.123	8
	4	**14**	**67**	0.133	0.083	13	0.500	0.000	2	0.500	0.000	1	0.500	0.000	5	0.265	0.173	3
	4	**14**	**68**	0.500	0.000	5	0.500	0.000	1	0.276	0.157	2	0.500	0.000	1	0.342	0.150	5
ROS	**(all)**			0.232	0.057	53	0.500	0.000	8	0.246	0.078	19	0.231	0.075	27	0.306	0.046	55
	1			0.394	0.096	10	0.500	0.000	2	0.000	0.000	0	0.500	0.000	2	0.262	0.117	9
	1	**3**		0.500	0.000	8	0.500	0.000	2	0.000	0.000	0	0.500	0.000	1	0.276	0.132	7
	2			0.221	0.094	16	0.500	0.000	2	0.315	0.167	2	0.199	0.125	3	0.272	0.191	3
	2	**7**		0.201	0.125	3	0.500	0.000	2	0.500	0.000	2	0.000	0.000	0	0.500	0.000	2
	2	**8**		0.248	0.123	8	0.000	0.000	0	0.500	0.000	0	0.188	0.115	3	0.240	0.197	3
	2	**8**	**36**	0.189	0.124	6	0.000	0.000	0	0.500	0.000	0	0.265	0.135	2	0.500	0.000	2
	3			0.500	0.000	7	0.500	0.000	3	0.500	0.000	3	0.348	0.144	5	0.251	0.148	5
	3	**11**		0.500	0.000	7	0.500	0.000	3	0.500	0.000	2	0.500	0.000	4	0.233	0.137	5
	3	**11**	**56**	0.500	0.000	6	0.500	0.000	3	0.500	0.000	2	0.500	0.000	4	0.195	0.145	4
	5			0.251	0.065	33	0.500	0.000	3	0.211	0.107	9	0.215	0.107	9	0.203	0.086	20
	5	**18**		0.248	0.067	32	0.500	0.000	3	0.229	0.112	8	0.301	0.120	8	0.237	0.090	17
	5	**18**	**93**	0.255	0.064	29	0.500	0.000	2	0.202	0.118	6	0.308	0.116	8	0.236	0.098	11
	5	**18**	**94**	0.368	0.124	6	0.500	0.000	1	0.500	0.000	1	0.500	0.000	2	0.500	0.000	5
	5	**20**		0.500	0.000	2	0.490	0.070	0	0.282	0.172	3	0.285	0.160	1	0.163	0.126	5
	5	**20**	**124**	0.500	0.000	2	0.000	0.000	0	0.272	0.187	3	0.243	0.140	1	0.165	0.135	5
	7			0.500	0.000	5	0.000	0.000	0	0.191	0.170	2	0.500	0.000	6	0.354	0.073	24

	7	**28**		0.500	0.000	5	0.490	0.070	0	0.200	0.162	2	0.500	0.000	6	0.250	0.117	9
	7	**28**	**153**	0.500	0.000	3	0.000	0.000	0	0.500	0.000	0	0.500	0.000	1	0.338	0.146	5
Photoactivity	**(all)**			0.373	0.115	7	0.500	0.000	1	0.272	0.187	3	0.139	0.108	7	0.230	0.105	14
	1			0.344	0.126	6	0.500	0.000	1	0.280	0.171	3	0.119	0.105	5	0.237	0.099	11
	1	**4**		0.364	0.118	6	0.500	0.000	1	0.282	0.183	3	0.128	0.102	5	0.242	0.106	11
	1	**4**	**28**	0.385	0.128	6	0.000	0.000	0	0.250	0.170	3	0.127	0.099	5	0.171	0.115	7
Membrane	**(all)**			0.448	0.021	91	0.500	0.000	14	0.377	0.076	18	0.415	0.058	22	0.453	0.030	42
	2			0.500	0.000	7	0.500	0.000	2	0.500	0.000	1	0.500	0.000	7	0.500	0.000	4
	2	**8**		0.500	0.000	6	0.500	0.000	1	0.500	0.000	1	0.500	0.000	7	0.500	0.000	4
	2	**8**	**36**	0.500	0.000	3	0.500	0.000	1	0.500	0.000	1	0.500	0.000	5	0.000	0.000	0
	2	**8**	**37**	0.500	0.000	3	0.000	0.000	0	0.000	0.000	0	0.500	0.000	4	0.500	0.000	4
	3			0.500	0.000	11	0.500	0.000	2	0.500	0.000	1	0.500	0.000	6	0.500	0.000	10
	3	**11**		0.500	0.000	11	0.500	0.000	2	0.500	0.000	1	0.500	0.000	6	0.500	0.000	10
	3	**11**	**53**	0.500	0.000	3	0.000	0.000	0	0.000	0.000	0	0.500	0.000	4	0.500	0.000	8
	3	**11**	**56**	0.500	0.000	7	0.500	0.000	2	0.500	0.000	1	0.500	0.000	4	0.500	0.000	5
	4			0.482	0.019	52	0.500	0.000	5	0.406	0.074	10	0.301	0.126	8	0.464	0.037	26
	4	**13**		0.466	0.034	27	0.500	0.000	2	0.354	0.116	6	0.500	0.000	5	0.500	0.000	17
	4	**13**	**64**	0.500	0.000	18	0.500	0.000	1	0.500	0.000	6	0.500	0.000	5	0.500	0.000	14
	4	**14**		0.466	0.030	30	0.500	0.000	3	0.500	0.000	4	0.280	0.188	3	0.424	0.069	13
	4	**14**	**67**	0.464	0.034	26	0.500	0.000	2	0.500	0.000	3	0.275	0.175	3	0.399	0.099	9
	4	**14**	**68**	0.500	0.000	4	0.500	0.000	1	0.500	0.000	1	0.000	0.000	0	0.500	0.000	4
	5			0.440	0.032	47	0.500	0.000	6	0.325	0.120	9	0.393	0.089	10	0.500	0.000	17
	5	**16**		0.441	0.043	29	0.500	0.000	4	0.328	0.154	5	0.381	0.106	8	0.500	0.000	11
	5	**16**	**80**	0.393	0.099	9	0.500	0.000	1	0.500	0.000	1	0.500	0.000	2	0.500	0.000	3
	5	**16**	**81**	0.285	0.160	2	0.480	0.098	2	0.500	0.000	1	0.500	0.000	3	0.500	0.000	3
	5	**16**	**83**	0.500	0.000	12	0.000	0.000	0	0.000	0.000	0	0.500	0.000	1	0.500	0.000	4
	5	**16**	**84**	0.500	0.000	9	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.500	0.000	1
	5	**18**		0.429	0.049	27	0.500	0.000	3	0.353	0.142	6	0.345	0.146	5	0.500	0.000	8
	5	**18**	**97**	0.402	0.066	18	0.500	0.000	2	0.368	0.119	6	0.500	0.000	2	0.500	0.000	6
DNA	**(all)**			0.274	0.080	24	0.500	0.000	6	0.205	0.164	2	0.251	0.138	5	0.141	0.097	4

	2			0.357	0.131	6	0.500	0.000	2	0.500	0.000	0	0.295	0.182	3	0.500	0.000	0
	5			0.202	0.120	9	0.500	0.000	3	0.500	0.000	2	0.248	0.251	1	0.199	0.132	2
	5	**17**		0.283	0.145	6	0.500	0.000	3	0.500	0.000	1	0.000	0.000	0	0.275	0.195	1
	5	**17**	**89**	0.211	0.137	3	0.500	0.000	3	0.500	0.000	1	0.000	0.000	0	0.260	0.180	1
Protein	**(all)**			0.453	0.030	43	0.500	0.000	7	0.223	0.143	5	0.219	0.133	7	0.433	0.071	15
	2			0.462	0.040	22	0.500	0.000	3	0.294	0.151	4	0.170	0.119	4	0.395	0.111	8
	2	**8**		0.425	0.069	13	0.000	0.000	0	0.330	0.145	4	0.173	0.135	3	0.325	0.166	5
	2	**8**	**36**	0.401	0.109	8	0.000	0.000	0	0.297	0.172	3	0.155	0.132	3	0.304	0.160	4
	2	**8**	**37**	0.500	0.000	6	0.000	0.000	0	0.500	0.000	1	0.252	0.251	1	0.500	0.000	1

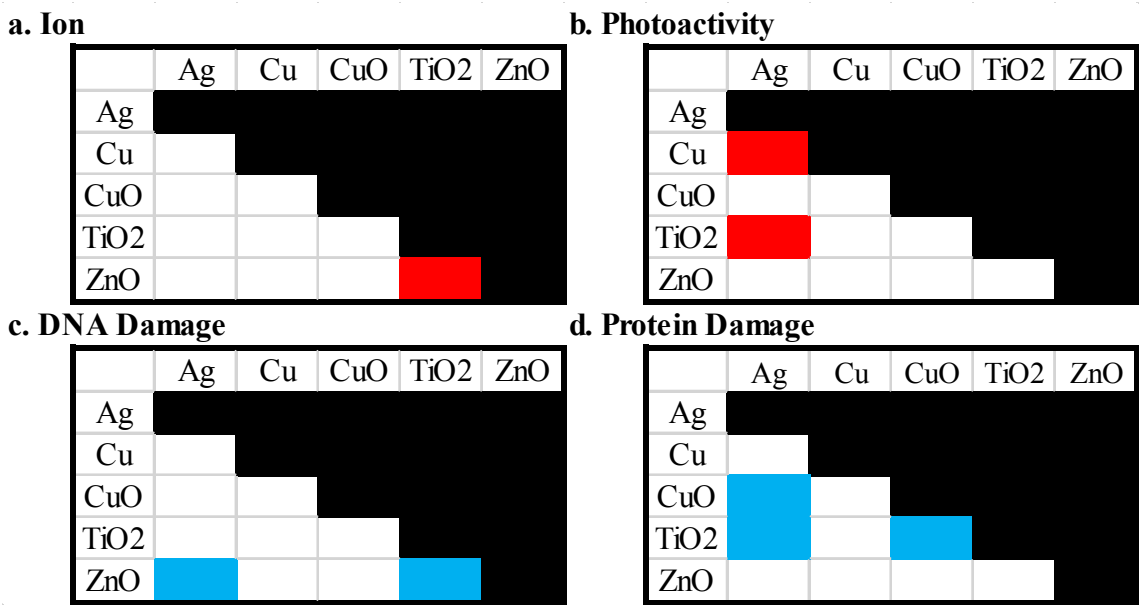

Figure S1. Statistically significant differences in conclusions based on ENM composition. Parts (a) through (d) show mechanism questions for which there were differences in conclusions between ENM compositions: ions (a), photoactivity (b), DNA damage (c), and protein damage (d). A blue cell indicates that the fraction of positive conclusions about the corresponding mechanism question was higher for the ENM composition on the horizontal axis versus the ENM composition on the vertical axis. A red cell indicates that the fraction of negative conclusions about the corresponding mechanism question was higher for the ENM composition on the horizontal axis versus the ENM composition on the vertical axis.

a. ENM particle size (dry, as measured by TEM)

	<10nm	10-20nm	20-30nm	30-40nm	40-50nm	>100nm	Compare multiple	Unspecified
Ion								ZnO
Particle				Ag		ZnO		
Internalization								
ROS			TiO2	TiO2	CuO		Ag	
Photoactivity	TiO2							
Membrane Damage								
DNA Damage	ZnO		ZnO					
Protein Damage								

b. ENM capping agent

	Uncapped	Unspecified
Ion		Cu
Particle		ZnO
Internalization		
ROS	TiO2	
Photoactivity		
Membrane Damage		
DNA Damage		
Protein Damage		

c. Bacterium used

	Gram positive	Gram negative	Both	Not specified
Ion				
Particle	ZnO	ZnO		
Internalization				
ROS			CuO	
Photoactivity		ZnO		
Membrane Damage		CuO, ZnO		
DNA Damage				
Protein Damage				

d. Characterization techniques

	SEM/TEM	DLS	Zeta potential	XRD	BET	UV-Vis	EDX	XPS	FTIR	PL Spectroscopy
Ion	ZnO				ZnO	Ag				ZnO
Particle	Cu					Ag				
Internalization										ZnO
ROS	TiO2	CuO / TiO2		Ag, TiO2	ZnO	TiO2	Ag	Ag		
Photoactivity					TiO2					
Membrane Damage										
DNA Damage			Ag						ZnO	
Protein Damage	TiO2									

e. Antibacterial activity assessment method

	Plating	Disk diffusion	Broth dilution	Membrane	Other	Multiple concentrations	Multiple time points
Ion			ZnO	Ag	Ag		
Particle							
Internalization			Ag				Ag
ROS							ZnO
Photoactivity							
Membrane Damage							
DNA Damage	ZnO					Ag	
Protein Damage							TiO2

f. Lighting conditions (used in mechanism-targeted experiments)

	Dark	Unspecified
Ion	Ag / ZnO	
Particle		
Internalization		ZnO
ROS		Ag
Photoactivity		
Membrane Damage		
DNA Damage		
Protein Damage	TiO2	

g. ENM hydrodynamic size (as measured by DLS)

	100-200nm	200-500nm	Compare multiple	Unspecified
Ion	ZnO		ZnO	
Particle				
Internalization				
ROS				ZnO
Photoactivity				
Membrane Damage				
DNA Damage				
Protein Damage				

h. Group number of mechanism-targeted experimental method (for explanation of method Groups, see Table S3 or Table 3)

	1	2	3	4	7
Ion		Ag			
Particle			CuO	ZnO	
Internalization					
ROS	Ag	TiO2			
Photoactivity					
Membrane Damage				Ag	
DNA Damage		Ag, TiO2			
Protein Damage					

Figure S2. Statistically significant differences in conclusions arising from selected study design variables, with different categories of study design variables (listed in Table 2 and Table S2) shown in parts (a) through (h). The eight mechanism questions are shown on the

vertical axis, and study design variables within each category are shown on the horizontal axis. Only variables which yielded a statistically significant difference in conclusions for at least one mechanism question, within at least one ENM composition, are included here; therefore, not all variables and categories listed in Table S2 are included. A blue cell indicates that the fraction of positive conclusions about the corresponding mechanism question was higher in the subset of studies for which the corresponding study design variable was true versus the subset of studies for which the corresponding study design variable was false, within the ENM composition group(s) specified. A red cell indicates that the fraction of negative conclusions about the corresponding mechanism question was higher in the subset of studies for which the corresponding study design variable was true versus the subset of studies for which the corresponding study design variable was false, within the ENM composition group(s) specified. A blank cell indicates that no statistically significant difference in conclusions was found for the corresponding mechanism question based on the corresponding study design variable, within any ENM composition group.

References

1. Ouyang, K., et al., *Effects of humic acid on the interactions between zinc oxide nanoparticles and bacterial biofilms.* Environmental Pollution, 2017. **231**: p. 1104-1111.
2. Agnihotri, S., S. Mukherji, and S. Mukherji, *Impact of background water quality on disinfection performance and silver release of immobilized silver nanoparticles: Modeling disinfection kinetics, bactericidal mechanism and aggregation behavior.* Chemical Engineering Journal, 2019. **372**: p. 684-696.
3. Xiu, Z.M., J. Ma, and P.J.J. Alvarez, *Differential Effect of Common Ligands and Molecular Oxygen on Antimicrobial Activity of Silver Nanoparticles versus Silver Ions.* Environmental Science & Technology, 2011. **45**(20): p. 9003-9008.
4. Smetana, A.B., et al., *Biocidal activity of nanocrystalline silver powders and particles.* Langmuir, 2008. **24**(14): p. 7457-7464.
5. Long, Y.M., et al., *Surface ligand controls silver ion release of nanosilver and its antibacterial activity against Escherichia coli.* International Journal of Nanomedicine, 2017. **12**: p. 3193-3206.
6. Choi, Y., et al., *Comparative toxicity of silver nanoparticles and silver ions to Escherichia coli.* Journal of Environmental Sciences, 2018. **66**: p. 50-60.
7. Bondarenko, O., et al., *Sub-toxic effects of CuO nanoparticles on bacteria: Kinetics, role of Cu ions and possible mechanisms of action.* Environmental Pollution, 2012. **169**: p. 81-89.
8. Calder, A.J., et al., *Soil components mitigate the antimicrobial effects of silver nanoparticles towards a beneficial soil bacterium, Pseudomonas chlororaphis O6.* Science of the total environment, 2012. **429**: p. 215-222.
9. Christena, L.R., et al., *Copper nanoparticles as an efflux pump inhibitor to tackle drug resistant bacteria.* Rsc Advances, 2015. **5**(17): p. 12899-12909.
10. Li, F.F., et al., *Analysis of copper nanoparticles toxicity based on a stress-responsive bacterial biosensor array.* Nanoscale, 2013. **5**(2): p. 653-662.
11. Barros, D., et al., *Proteomics and antioxidant enzymes reveal different mechanisms of toxicity induced by ionic and nanoparticulate silver in bacteria.* Environmental Science-Nano, 2019. **6**(4): p. 1207-1218.
12. Arnaout, C.L. and C.K. Gunsch, *Impacts of Silver Nanoparticle Coating on the Nitrification Potential of Nitrosomonas europaea.* Environmental Science & Technology, 2012. **46**(10): p. 5387-5395.
13. Zhao, X., T. Toyooka, and Y. Ibuki, *Synergistic bactericidal effect by combined exposure to Ag nanoparticles and UVA.* Science of The Total Environment, 2013. **458-460**: p. 54-62.
14. Dimkpa, C.O., et al., *Responses of a soil bacterium, Pseudomonas chlororaphis O6 to commercial metal oxide nanoparticles compared with responses to metal ions.* Environmental pollution, 2011. **159**(7): p. 1749-1756.
15. Wang, D., et al., *Quantitative Analysis of Reactive Oxygen Species Photogenerated on Metal Oxide Nanoparticles and Their Bacteria Toxicity: The Role of Superoxide Radicals.* Environmental Science & Technology, 2017. **51**(17): p. 10137-10145.
16. Agnihotri, S., S. Mukherji, and S. Mukherji, *Immobilized silver nanoparticles enhance contact killing and show highest efficacy: elucidation of the mechanism of bactericidal action of silver.* Nanoscale, 2013. **5**(16): p. 7328-7340.

17. Taglietti, A., et al., *Antibacterial Activity of Glutathione-Coated Silver Nanoparticles against Gram Positive and Gram Negative Bacteria.* Langmuir, 2012. **28**(21): p. 8140-8148.
18. Chen, L.K., et al., *A Comparative Toxicity Study of TiO2 Nanoparticles in Suspension and Adherent Culture Under the Dark Condition.* Chemical Research in Chinese Universities, 2018. **34**(1): p. 44-50.
19. Gilbertson, L.M., et al., *Shape-Dependent Surface Reactivity and Antimicrobial Activity of Nano-Cupric Oxide.* Environmental Science & Technology, 2016. **50**(7): p. 3975-3984.
20. Gunawan, C., et al., *Cytotoxic origin of copper (II) oxide nanoparticles: comparative studies with micron-sized particles, leachate, and metal salts.* ACS nano, 2011. **5**(9): p. 7214-7225.
21. Kadiyala, U., et al., *Unexpected insights into antibacterial activity of zinc oxide nanoparticles against methicillin resistant Staphylococcus aureus (MRSA).* Nanoscale, 2018. **10**(10): p. 4927-4939.
22. Liu, X.M., et al., *Mechanisms of oxidative stress caused by CuO nanoparticles to membranes of the bacterium Streptomyces coelicolor M145.* Ecotoxicology and Environmental Safety, 2018. **158**: p. 123-130.
23. Pasquet, J., et al., *The contribution of zinc ions to the antimicrobial activity of zinc oxide.* Colloids and Surfaces a-Physicochemical and Engineering Aspects, 2014. **457**: p. 263-274.
24. Khan, S.S., S.S. Ghouse, and P. Chandran, *Toxic effect of environmentally relevant concentration of silver nanoparticles on environmentally beneficial bacterium Pseudomonas putida.* Bioprocess and Biosystems Engineering, 2015. **38**(7): p. 1243-1249.
25. Liu, Y., et al., *Antibacterial activities of zinc oxide nanoparticles against Escherichia coli O157:H7.* Journal of Applied Microbiology, 2009. **107**(4): p. 1193-1201.
26. Nagy, A., et al., *Silver nanoparticles embedded in zeolite membranes: release of silver ions and mechanism of antibacterial action.* International Journal of Nanomedicine, 2011. **6**: p. 1833-1852.
27. Visnapuu, M., et al., *Dissolution of Silver Nanowires and Nanospheres Dictates Their Toxicity to Escherichia coli.* Biomed Research International, 2013.
28. Jiang, Y.H., et al., *Role of physical and chemical interactions in the antibacterial behavior of ZnO nanoparticles against E. coli.* Materials Science & Engineering C-Materials for Biological Applications, 2016. **69**: p. 1361-1366.
29. Bondarenko, O., et al., *Particle-Cell Contact Enhances Antibacterial Activity of Silver Nanoparticles.* Plos One, 2013. **8**(5).
30. Zhang, L.L., et al., *Mechanistic investigation into antibacterial behaviour of suspensions of ZnO nanoparticles against E. coli.* Journal of Nanoparticle Research, 2010. **12**(5): p. 1625-1636.
31. Bae, E., et al., *Bacterial cytotoxicity of the silver nanoparticle related to physicochemical metrics and agglomeration properties.* Environmental Toxicology and Chemistry, 2010. **29**(10): p. 2154-2160.
32. Ulloa-Ogaz, A.L., et al., *Oxidative damage to Pseudomonas aeruginosa ATCC 27833 and Staphylococcus aureus ATCC 24213 induced by CuO-NPs.* Environmental Science and Pollution Research, 2017. **24**(27): p. 22048-22060.

33. Dror-Ehre, A., et al., *Silver nanoparticle-E. coli colloidal interaction in water and effect on E-coli survival.* Journal of Colloid and Interface Science, 2009. **339**(2): p. 521-526.
34. Fabrega, J., et al., *Silver nanoparticle impact on bacterial growth: effect of pH, concentration, and organic matter.* Environmental science & technology, 2009. **43**(19): p. 7285-7290.
35. Kim, J.S., et al., *Antimicrobial effects of silver nanoparticles.* Nanomedicine-Nanotechnology Biology and Medicine, 2007. **3**(1): p. 95-101.
36. McQuillan, J.S., et al., *Silver nanoparticle enhanced silver ion stress response in Escherichia coli K12.* Nanotoxicology, 2012. **6**(8): p. 857-866.
37. Hossain, M.I., et al., *Antimicrobial properties of nanorods: killing bacteria via impalement.* Iet Nanobiotechnology, 2017. **11**(5): p. 501-505.
38. Xiu, Z.M., et al., *Negligible Particle-Specific Antibacterial Activity of Silver Nanoparticles.* Nano Letters, 2012. **12**(8): p. 4271-4275.
39. Xu, H.Y., et al., *Role of reactive oxygen species in the antibacterial mechanism of silver nanoparticles on Escherichia coli O157:H7.* Biometals, 2012. **25**(1): p. 45-53.
40. Hwang, E.T., et al., *Analysis of the toxic mode of action of silver nanoparticles using stress-specific bioluminescent bacteria.* Small, 2008. **4**(6): p. 746-750.
41. Ajdari, M.R., et al., *Phytosynthesis of Silver Nanoparticles Using Myrtus communis L. Leaf Extract and Investigation of Bactericidal Activity.* Journal of Electronic Materials, 2017. **46**(12): p. 6930-6935.
42. Baek, S., S.H. Joo, and M. Toborek, *Treatment of antibiotic-resistant bacteria by encapsulation of ZnO nanoparticles in an alginate biopolymer: Insights into treatment mechanisms.* Journal of Hazardous Materials, 2019. **373**: p. 122-130.
43. Loo, S.L., et al., *Bactericidal Mechanisms Revealed for Rapid Water Disinfection by Superabsorbent Cryogels Decorated with Silver Nanoparticles.* Environmental Science & Technology, 2015. **49**(4): p. 2310-2318.
44. Lia, S.J., et al., *Antibacterial activity and mechanism of silver nanoparticles against multidrug-resistant Pseudomonas aeruginosa.* International Journal of Nanomedicine, 2019. **14**: p. 1469-1487.
45. Singh, M., *Elucidation of biogenic silver nanoparticles susceptibility towards Escherichia coli: an investigation on the antimicrobial mechanism.* Iet Nanobiotechnology, 2016. **10**(5): p. 276-280.
46. Prasanna, V.L. and R. Vijayaraghavan, *Insight into the Mechanism of Antibacterial Activity of ZnO: Surface Defects Mediated Reactive Oxygen Species Even in the Dark.* Langmuir, 2015. **31**(33): p. 9155-9162.
47. Hessler, C.M., et al., *The influence of capsular extracellular polymeric substances on the interaction between TiO2 nanoparticles and planktonic bacteria.* Water Research, 2012. **46**(15): p. 4687-4696.
48. Quek, J.A., et al., *Visible light responsive flower-like ZnO in photocatalytic antibacterial mechanism towards Enterococcus faecalis and Micrococcus luteus.* Journal of Photochemistry and Photobiology B-Biology, 2018. **187**: p. 66-75.
49. Zhang, L.L., et al., *The properties of ZnO nanofluids and the role of H2O2 in the disinfection activity against Escherichia coli.* Water Research, 2013. **47**(12): p. 4013-4021.

50. Wong, K.A., S.M. Lam, and J.C. Sin, *Wet chemically synthesized ZnO structures for photodegradation of pre-treated palm oil mill effluent and antibacterial activity.* Ceramics International, 2019. **45**(2): p. 1868-1880.
51. Ronen, A., R. Semiat, and C.G. Dosoretz, *Antibacterial efficiency of composite nano-ZnO in biofilm development in flow-through systems.* Desalination and Water Treatment, 2013. **51**(4-6): p. 988-996.
52. Lv, Q., et al., *Biosynthesis of copper nanoparticles using Shewanella loihica PV-4 with antibacterial activity: Novel approach and mechanisms investigation.* Journal of Hazardous Materials, 2018. **347**: p. 141-149.
53. Barnes, R.J., et al., *Comparison of TiO 2 and ZnO nanoparticles for photocatalytic degradation of methylene blue and the correlated inactivation of gram-positive and gram-negative bacteria.* Journal of nanoparticle research, 2013. **15**(2): p. 1432.
54. Kim, S.W. and Y.-J. An, *Effect of ZnO and TiO 2 nanoparticles preilluminated with UVA and UVB light on Escherichia coli and Bacillus subtilis.* Applied microbiology and biotechnology, 2012. **95**(1): p. 243-253.
55. Veerapandian, M., et al., *Glucosamine functionalized copper nanoparticles: Preparation, characterization and enhancement of anti-bacterial activity by ultraviolet irradiation.* Chemical Engineering Journal, 2012. **209**: p. 558-567.
56. Zhang, L.L., et al., *ZnO nanofluids - A potential antibacterial agent.* Progress in Natural Science-Materials International, 2008. **18**(8): p. 939-944.
57. Akhavan, O. and E. Ghaderi, *Cu and CuO nanoparticles immobilized by silica thin films as antibacterial materials and photocatalysts.* Surface & Coatings Technology, 2010. **205**(1): p. 219-223.
58. Dasari, T.P., K. Pathakoti, and H.M. Hwang, *Determination of the mechanism of photoinduced toxicity of selected metal oxide nanoparticles (ZnO, CuO, Co3O4 and TiO2) to E-coli bacteria.* Journal of Environmental Sciences-China, 2013. **25**(5): p. 882-888.
59. Li, Y., et al., *Mechanism of Photogenerated Reactive Oxygen Species and Correlation with the Antibacterial Properties of Engineered Metal-Oxide Nanoparticles.* Acs Nano, 2012. **6**(6): p. 5164-5173.
60. Li, Y., et al., *Influence of aqueous media on the ROS-mediated toxicity of ZnO nanoparticles toward green fluorescent protein-expressing Escherichia coli under UV-365 irradiation.* Langmuir, 2014. **30**(10): p. 2852-2862.
61. Shang, E.X., et al., *Effect of aqueous media on the copper-ion-mediated phototoxicity of CuO nanoparticles toward green fluorescent protein-expressing Escherichia coli.* Ecotoxicology and Environmental Safety, 2015. **122**: p. 238-244.
62. Al-Sharqi, A., et al., *Enhancement of the Antibacterial Efficiency of Silver Nanoparticles against Gram-Positive and Gram-Negative Bacteria Using Blue Laser Light.* International Journal of Photoenergy, 2019.
63. Dalai, S., et al., *Studies on interfacial interactions of TiO2 nanoparticles with bacterial cells under light and dark conditions.* Bulletin of Materials Science, 2014. **37**(3): p. 371-381.
64. Dasari, T.P. and H.M. Hwang, *The effect of humic acids on the cytotoxicity of silver nanoparticles to a natural aquatic bacterial assemblage.* Science of the Total Environment, 2010. **408**(23): p. 5817-5823.

65. Erdem, A., et al., *Inhibition of bacteria by photocatalytic nano-TiO2 particles in the absence of light.* International Journal of Environmental Science and Technology, 2015. **12**(9): p. 2987-2996.
66. Erdem, A., et al., *The short-term toxic effects of TiO2 nanoparticles toward bacteria through viability, cellular respiration, and lipid peroxidation.* Environmental Science and Pollution Research, 2015. **22**(22): p. 17917-17924.
67. Gedik, G., et al., *Production of Metal Oxide Containing Antibacterial Coated Textile Material and Investigation of the Mechanism of Action.* Fibers and Polymers, 2018. **19**(12): p. 2548-2563.
68. Jalvo, B., et al., *Antimicrobial and antibiofilm efficacy of self-cleaning surfaces functionalized by TiO2 photocatalytic nanoparticles against Staphylococcus aureus and Pseudomonas putida.* Journal of Hazardous Materials, 2017. **340**: p. 160-170.
69. Joe, A., et al., *Antimicrobial activity of ZnO nanoplates and its Ag nanocomposites: Insight into an ROS-mediated antibacterial mechanism under UV light.* Journal of Solid State Chemistry, 2018. **267**: p. 124-133.
70. Joost, U., et al., *Photocatalytic antibacterial activity of nano-TiO2 (anatase)-based thin films: Effects on Escherichia coli cells and fatty acids.* Journal of Photochemistry and Photobiology B-Biology, 2015. **142**: p. 178-185.
71. Leung, Y.H., et al., *Toxicity of ZnO and TiO2 to Escherichia coli cells.* Scientific Reports, 2016. **6**.
72. McQuillan, J.S. and A.M. Shaw, *Whole-cell Escherichia coli-based bio-sensor assay for dual zinc oxide nanoparticle toxicity mechanisms.* Biosensors & Bioelectronics, 2014. **51**: p. 274-279.
73. Nesic, J., et al., *New evidence for TiO2 uniform surfaces leading to complete bacterial reduction in the dark: Critical issues.* Colloids and Surfaces B-Biointerfaces, 2014. **123**: p. 593-599.
74. Pathakoti, K., et al., *Using experimental data of Escherichia coli to develop a QSAR model for predicting the photo-induced cytotoxicity of metal oxide nanoparticles.* Journal of Photochemistry and Photobiology B-Biology, 2014. **130**: p. 234-240.
75. Qiu, T.A., et al., *A mechanistic study of TiO2 nanoparticle toxicity on Shewanella oneidensis MR-1 with UV-containing simulated solar irradiation: Bacterial growth, riboflavin secretion, and gene expression.* Chemosphere, 2017. **168**: p. 1158-1168.
76. Rocca, D.M., et al., *Biocompatibility and photo-induced antibacterial activity of lignin-stabilized noble metal nanoparticles.* Rsc Advances, 2018. **8**(70): p. 40454-40463.
77. Valenzuela, L., et al., *Antimicrobial surfaces with self-cleaning properties functionalized by photocatalytic ZnO electrosprayed coatings.* Journal of Hazardous Materials, 2019. **369**: p. 665-673.
78. Visinescu, D., et al., *Zinc Oxide Spherical-Shaped Nanostructures: Investigation of Surface Reactivity and Interactions with Microbial and Mammalian Cells.* Langmuir, 2018. **34**(45): p. 13638-13651.
79. Zhang, W., et al., *Photogeneration of Reactive Oxygen Species on Uncoated Silver, Gold, Nickel, and Silicon Nanoparticles and Their Antibacterial Effects.* Langmuir, 2013. **29**(15): p. 4647-4651.
80. Zhukova, L.V., *Evidence for Compression of Escherichia coli K12 Cells under the Effect of TiO2 Nanoparticles.* Acs Applied Materials & Interfaces, 2015. **7**(49): p. 27197-27205.

81. Vijay, M., et al., *Photocatalytic inactivation of Gram-positive and Gram-negative bacteria by reactive plasma processed nanocrystalline TiO2 powder.* Current Applied Physics, 2013. **13**(3): p. 510-516.
82. Rago, I., et al., *Zinc oxide microrods and nanorods: different antibacterial activity and their mode of action against Gram-positive bacteria.* Rsc Advances, 2014. **4**(99): p. 56031-56040.
83. Applerot, G., et al., *Understanding the Antibacterial Mechanism of CuO Nanoparticles: Revealing the Route of Induced Oxidative Stress.* Small, 2012. **8**(21): p. 3326-3337.
84. Bandyopadhyay, S., et al., *Comparative toxicity assessment of CeO2 and ZnO nanoparticles towards Sinorhizobium meliloti, a symbiotic alfalfa associated bacterium: use of advanced microscopic and spectroscopic techniques.* Journal of hazardous materials, 2012. **241**: p. 379-386.
85. Benakashani, F., A.R. Allafchian, and S.A.H. Jalali, *Biosynthesis of silver nanoparticles using Capparis spinosa L. leaf extract and their antibacterial activity.* Karbala International Journal of Modern Science, 2016. **2**(4): p. 251-258.
86. Bowman, C.R., et al., *Effects of silver nanoparticles on zebrafish (Danio rerio) and Escherichia coli (ATCC 25922): A comparison of toxicity based on total surface area versus mass concentration of particles in a model eukaryotic and prokaryotic system.* Environmental toxicology and chemistry, 2012. **31**(8): p. 1793-1800.
87. Chen, Y.G., et al., *The impacts of silver nanoparticles and silver ions on wastewater biological phosphorous removal and the mechanisms.* Journal of Hazardous Materials, 2012. **239**: p. 88-94.
88. Choi, O. and Z. Hu, *Size dependent and reactive oxygen species related nanosilver toxicity to nitrifying bacteria.* Environmental science & technology, 2008. **42**(12): p. 4583-4588.
89. El Badawy, A.M., et al., *Surface Charge-Dependent Toxicity of Silver Nanoparticles.* Environmental Science & Technology, 2011. **45**(1): p. 283-287.
90. Heinlaan, M., et al., *Toxicity of nanosized and bulk ZnO, CuO and TiO2 to bacteria Vibrio fischeri and crustaceans Daphnia magna and Thamnocephalus platyurus.* Chemosphere, 2008. **71**(7): p. 1308-1316.
91. Hsueh, Y.H., P.H. Tsai, and K.S. Lin, *pH-Dependent Antimicrobial Properties of Copper Oxide Nanoparticles in Staphylococcus aureus.* International Journal of Molecular Sciences, 2017. **18**(4).
92. Ivask, A., et al., *Profiling of the reactive oxygen species-related ecotoxicity of CuO, ZnO, TiO2, silver and fullerene nanoparticles using a set of recombinant luminescent Escherichia coli strains: differentiating the impact of particles and solubilised metals.* Analytical and Bioanalytical Chemistry, 2010. **398**(2): p. 701-716.
93. Ivask, A., et al., *Toxicity Mechanisms in Escherichia coli Vary for Silver Nanoparticles and Differ from Ionic Silver.* Acs Nano, 2014. **8**(1): p. 374-386.
94. Ivask, A., et al., *Size-Dependent Toxicity of Silver Nanoparticles to Bacteria, Yeast, Algae, Crustaceans and Mammalian Cells In Vitro.* Plos One, 2014. **9**(7).
95. Jiang, W., H. Mashayekhi, and B.S. Xing, *Bacterial toxicity comparison between nano- and micro-scaled oxide particles.* Environmental Pollution, 2009. **157**(5): p. 1619-1625.
96. Joe, A., et al., *Antibacterial mechanism of ZnO nanoparticles under dark conditions.* Journal of Industrial and Engineering Chemistry, 2017. **45**: p. 430-439.

97. Lok, C.-N., et al., *Proteomic analysis of the mode of antibacterial action of silver nanoparticles.* Journal of proteome research, 2006. **5**(4): p. 916-924.
98. Meghana, S., et al., *Understanding the pathway of antibacterial activity of copper oxide nanoparticles.* Rsc Advances, 2015. **5**(16): p. 12293-12299.
99. Moore, J.D., et al., *Time-dependent bacterial transcriptional response to CuO nanoparticles differs from that of Cu2+ and provides insights into CuO nanoparticle toxicity mechanisms.* Environmental Science-Nano, 2017. **4**(12): p. 2321-2335.
100. Morones, J.R., et al., *The bactericidal effect of silver nanoparticles.* Nanotechnology, 2005. **16**(10): p. 2346.
101. Neal, A.L., et al., *Can the soil bacterium Cupriavidus necator sense ZnO nanomaterials and aqueous Zn2+ differentially?* Nanotoxicology, 2012. **6**(4): p. 371-380.
102. Padmavathy, N. and R. Vijayaraghavan, *Enhanced bioactivity of ZnO nanoparticles—an antimicrobial study.* Science and technology of advanced materials, 2008. **9**(3): p. 035004.
103. Rousk, J., et al., *Comparative Toxicity of Nanoparticulate CuO and ZnO to Soil Bacterial Communities.* Plos One, 2012. **7**(3).
104. Su, Y.L., et al., *Alteration of intracellular protein expressions as a key mechanism of the deterioration of bacterial denitrification caused by copper oxide nanoparticles.* Scientific Reports, 2015. **5**.
105. Alqahtany, M., et al., *Nanoscale reorganizations of histone-like nucleoid structuring proteins in Escherichia coli are caused by silver nanoparticles.* Nanotechnology, 2019. **30**(38).
106. Bondarenko, O.M., et al., *Plasma membrane is the target of rapid antibacterial action of silver nanoparticles in Escherichia coil and Pseudomonas aeruginosa.* International Journal of Nanomedicine, 2018. **13**: p. 6779-6790.
107. Carlos, A.Q., et al., *Toxicity Effects in Pathogen Microorganisms Exposed to Silver Nanoparticles.* Nanoscience and Nanotechnology Letters, 2017. **9**(2): p. 165-173.
108. Chen, J.N., et al., *Enhancement of the Antibacterial Activity of Silver Nanoparticles against Phytopathogenic Bacterium Ralstonia solanacearum by Stabilization.* Journal of Nanomaterials, 2016.
109. Dimkpa, C.O., et al., *CuO and ZnO nanoparticles differently affect the secretion of fluorescent siderophores in the beneficial root colonizer, Pseudomonas chlororaphis O6.* Nanotoxicology, 2012. **6**(6): p. 635-642.
110. Doody, M.A., et al., *Differential antimicrobial activity of silver nanoparticles to bacteria Bacillus subtilis and Escherichia coli, and toxicity to crop plant Zea mays and beneficial B. subtilis-inoculated Z. mays.* Journal of Nanoparticle Research, 2016. **18**(10).
111. Dutta, R.K., et al., *Antibacterial effect of chronic exposure of low concentration ZnO nanoparticles on E. coli.* Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering, 2013. **48**(8): p. 871-878.
112. Gelabert, A., et al., *Testing nanoeffect onto model bacteria: Impact of speciation and genotypes.* Nanotoxicology, 2016. **10**(2): p. 216-225.
113. Giao, N.T., et al., *Influence of silver nanoparticles and liberated silver ions on nitrifying sludge: ammonia oxidation inhibitory kinetics and mechanism.* Environmental Science and Pollution Research, 2017. **24**(10): p. 9229-9240.

114. Guo, Y.T., et al., *Heterogenic response of prokaryotes toward silver nanoparticles and ions is facilitated by phenotypes and attachment of silver aggregates to cell surfaces.* Cytometry Part A, 2017. **91A**(8): p. 775-784.
115. Joshi, N., et al., *Use of bioreporters and deletion mutants reveals ionic silver and ROS to be equally important in silver nanotoxicity.* Journal of Hazardous Materials, 2015. **287**: p. 51-58.
116. Li, H.Y., et al., *A comparative study of the antibacterial mechanisms of silver ion and silver nanoparticles by Fourier transform infrared spectroscopy.* Vibrational Spectroscopy, 2016. **85**: p. 112-121.
117. Mapara, N., et al., *Antimicrobial potentials of Helicteres isora silver nanoparticles against extensively drug-resistant (XDR) clinical isolates of Pseudomonas aeruginosa.* Applied Microbiology and Biotechnology, 2015. **99**(24): p. 10655-10667.
118. McQuillan, J.S. and A.M. Shaw, *Differential gene regulation in the Ag nanoparticle and Ag+-induced silver stress response in Escherichia coli: A full transcriptomic profile.* Nanotoxicology, 2014. **8**: p. 177-184.
119. Mosselhy, D.A., et al., *Comparative synthesis and antimicrobial action of silver nanoparticles and silver nitrate.* Journal of Nanoparticle Research, 2015. **17**(12).
120. Mu, H. and Y.G. Chen, *Long-term effect of ZnO nanoparticles on waste activated sludge anaerobic digestion.* Water Research, 2011. **45**(17): p. 5612-5620.
121. Qin, Q., J.Y. Li, and J.B. Wang, *Antibacterial Activity Comparison of Three Metal Oxide Nanoparticles and their Dissolved Metal Ions.* Water Environment Research, 2017. **89**(4): p. 378-383.
122. Radniecki, T.S., et al., *Influence of liberated silver from silver nanoparticles on nitrification inhibition of Nitrosomonas europaea.* Chemosphere, 2011. **85**(1): p. 43-49.
123. Singh, N., K.M. Paknikar, and J. Rajwade, *Gene expression is influenced due to 'nano' and 'ionic' copper in pre-formed Pseudomonas aeruginosa biofilms.* Environmental Research, 2019. **175**: p. 367-375.
124. Su, G.Y., et al., *Comparison on the molecular response profiles between nano zinc oxide (ZnO) particles and free zinc ion using a genome-wide toxicogenomics approach.* Environmental Science and Pollution Research, 2015. **22**(22): p. 17434-17442.
125. Svetlichnyi, V., et al., *ZnO nanoparticles obtained by pulsed laser ablation and their composite with cotton fabric: Preparation and study of antibacterial activity.* Applied Surface Science, 2016. **372**: p. 20-29.
126. Wang, H., et al., *Silver nanoparticles: A novel antibacterial agent for control of Cronobacter sakazakii.* Journal of Dairy Science, 2018. **101**(12): p. 10775-10791.
127. Wang, J.A., et al., *Effects of Silver Nanoparticles on Soil Microbial Communities and Bacterial Nitrification in Suburban Vegetable Soils.* Pedosphere, 2017. **27**(3): p. 482-490.
128. Yan, X.T., et al., *Antibacterial mechanism of silver nanoparticles in Pseudomonas aeruginosa: proteomics approach.* Metallomics, 2018. **10**(4): p. 557-564.
129. Zhao, J., et al., *Mitigation of CuO nanoparticle-induced bacterial membrane damage by dissolved organic matter.* Water Research, 2013. **47**(12): p. 4169-4178.
130. Dimkpa, C.O., et al., *Interaction of silver nanoparticles with an environmentally beneficial bacterium, Pseudomonas chlororaphis.* Journal of Hazardous Materials, 2011. **188**(1-3): p. 428-435.
131. Hwang, I.-s., et al., *Synergistic effects between silver nanoparticles and antibiotics and the mechanisms involved.* Journal of medical microbiology, 2012. **61**(12): p. 1719-1726.

132. Jin, J.C., et al., *One-step synthesis of silver nanoparticles using carbon dots as reducing and stabilizing agents and their antibacterial mechanisms.* Carbon, 2015. **94**: p. 129-141.
133. Reddy, L.S., et al., *Antimicrobial activity of zinc oxide (ZnO) nanoparticle against Klebsiella pneumoniae.* Pharmaceutical Biology, 2014. **52**(11): p. 1388-1397.
134. Kim, S. and Y. Yoon, *Assessing bioavailability and genotoxicity of heavy metals and metallic nanoparticles simultaneously using dual-sensing Escherichia coli whole-cell bioreporters.* Applied Biological Chemistry, 2016. **59**(4): p. 661-668.
135. Kubo, A.L., et al., *Antimicrobial potency of differently coated 10 and 50 nm silver nanoparticles against clinically relevant bacteria Escherichia coli and Staphylococcus aureus.* Colloids and Surfaces B-Biointerfaces, 2018. **170**: p. 401-410.
136. Deryabin, D., et al., *Investigation of copper nanoparticles antibacterial mechanisms tested by luminescent Escherichia coli strains.* Nanotechnologies in Russia, 2013. **8**(5-6): p. 402-408.
137. Radzig, M.A., et al., *Antibacterial effects of silver nanoparticles on gram-negative bacteria: Influence on the growth and biofilms formation, mechanisms of action.* Colloids and Surfaces B-Biointerfaces, 2013. **102**: p. 300-306.
138. Raghupathi, K.R., R.T. Koodali, and A.C. Manna, *Size-Dependent Bacterial Growth Inhibition and Mechanism of Antibacterial Activity of Zinc Oxide Nanoparticles.* Langmuir, 2011. **27**(7): p. 4020-4028.
139. Singh, N., K.M. Paknikar, and J. Rajwade, *RNA-sequencing reveals a multitude of effects of silver nanoparticles on Pseudomonas aeruginosa biofilms.* Environmental Science-Nano, 2019. **6**(6): p. 1812-1828.
140. Chambers, B.A., et al., *Effects of chloride and ionic strength on physical morphology, dissolution, and bacterial toxicity of silver nanoparticles.* Environmental science & technology, 2013. **48**(1): p. 761-769.
141. Fajardo, C., et al., *Impact of Ag and Al2O3 nanoparticles on soil organisms: In vitro and soil experiments.* Science of The Total Environment, 2014. **473-474**: p. 254-261.
142. Yang, Y., et al., *Impacts of silver nanoparticles on cellular and transcriptional activity of nitrogen-cycling bacteria.* Environmental toxicology and chemistry, 2013. **32**(7): p. 1488-1494.
143. Gou, N. and A.Z. Gu, *A New Transcriptional Effect Level Index (TELI) for Toxicogenomics-based Toxicity Assessment.* Environmental Science & Technology, 2011. **45**(12): p. 5410-5417.
144. Gou, N., A. Onnis-Hayden, and A.Z. Gu, *Mechanistic Toxicity Assessment of Nanomaterials by Whole-Cell-Array Stress Genes Expression Analysis.* Environmental Science & Technology, 2010. **44**(15): p. 5964-5970.
145. Sohm, B., et al., *Insight into the primary mode of action of TiO2 nanoparticles on Escherichia coli in the dark.* Proteomics, 2015. **15**(1): p. 98-113.
146. Qin, Y.K., et al., *Cytotoxicity of TiO2 nanoparticles toward Escherichia coli in an aquatic environment: effects of nanoparticle structural oxygen deficiency and aqueous salinity.* Environmental Science-Nano, 2017. **4**(5): p. 1178-1188.
147. Soni, D., et al., *STRESS RESPONSE OF PSEUDOMONAS SPECIES TO SILVER NANOPARTICLES AT THE MOLECULAR LEVEL.* Environmental Toxicology and Chemistry, 2014. **33**(9): p. 2126-2132.
148. Kubacka, A., et al., *Understanding the antimicrobial mechanism of TiO2-based nanocomposite films in a pathogenic bacterium.* Scientific Reports, 2014. **4**.

149. Lee, W., K.J. Kim, and D.G. Lee, *A novel mechanism for the antibacterial effect of silver nanoparticles on Escherichia coli.* Biometals, 2014. **27**(6): p. 1191-1201.
150. Yu, R., et al., *Short-term effects of TiO2, CeO2, and ZnO nanoparticles on metabolic activities and gene expression of Nitrosomonas europaea.* Chemosphere, 2015. **128**: p. 207-215.
151. Zhang, L., et al., *Size-dependent cytotoxicity of silver nanoparticles to Azotobacter vinelandii: Growth inhibition, cell injury, oxidative stress and internalization.* Plos One, 2018. **13**(12).
152. Li, W.R., et al., *Antibacterial effect of silver nanoparticles on Staphylococcus aureus.* Biometals, 2011. **24**(1): p. 135-141.
153. Mirzajani, F., et al., *Proteomics study of silver nanoparticles toxicity on Bacillus thuringiensis.* Ecotoxicology and Environmental Safety, 2014. **100**: p. 122-130.
154. Vidovic, S., et al., *ZnO Nanoparticles Impose a Panmetabolic Toxic Effect Along with Strong Necrosis, Inducing Activation of the Envelope Stress Response in Salmonella enterica Serovar Enteritidis.* Antimicrobial Agents and Chemotherapy, 2015. **59**(6): p. 3317-3328.
155. Patra, P., et al., *Damage of lipopolysaccharides in outer cell membrane and production of ROS-mediated stress within bacteria makes nano zinc oxide a bactericidal agent.* Applied Nanoscience, 2015. **5**(7): p. 857-866.
156. Yuan, Y.G., Q.L. Peng, and S. Gurunathan, *Effects of Silver Nanoparticles on Multiple Drug-Resistant Strains of Staphylococcus aureus and Pseudomonas aeruginosa from Mastitis-Infected Goats: An Alternative Approach for Antimicrobial Therapy.* International Journal of Molecular Sciences, 2017. **18**(3).
157. Jain, N., et al., *Removal of Protein Capping Enhances the Antibacterial Efficiency of Biosynthesized Silver Nanoparticles.* Plos One, 2015. **10**(7).
158. Alum, A., A. Alboloushi, and M. Abbaszadegan, *Copper nanoparticles toxicity: Laboratory strains verses environmental bacterial isolates.* Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering, 2018. **53**(7): p. 643-650.
159. Gomaa, E.Z., *Silver nanoparticles as an antimicrobial agent: A case study on Staphylococcus aureus and Escherichia coli as models for Gram-positive and Gram-negative bacteria.* Journal of General and Applied Microbiology, 2017. **63**(1): p. 36-43.
160. Thombre, R.S., et al., *Antimicrobial Activity and Mechanism of Inhibition of Silver Nanoparticles against Extreme Halophilic Archaea.* Frontiers in Microbiology, 2016. **7**.
161. Li, W.R., et al., *Antibacterial activity and mechanism of silver nanoparticles on Escherichia coli.* Applied Microbiology and Biotechnology, 2010. **85**(4): p. 1115-1122.
162. Cha, S.H., et al., *Shape-Dependent Biomimetic Inhibition of Enzyme by Nanoparticles and Their Antibacterial Activity.* Acs Nano, 2015. **9**(9): p. 9097-9105.
163. Khan, S.T., et al., *SYNTHESIS AND CHARACTERIZATION OF SOME ABUNDANT NANOPARTICLES, THEIR ANTIMICROBIAL AND ENZYME INHIBITION ACTIVITY.* Acta Microbiologica Et Immunologica Hungarica, 2017. **64**(2): p. 203-216.
164. Clar, J.G., et al., *Copper nanoparticle induced cytotoxicity to nitrifying bacteria in wastewater treatment: a mechanistic copper speciation study by X-ray absorption spectroscopy.* Environmental science & technology, 2016. **50**(17): p. 9105-9113.
165. Hsueh, Y.H., et al., *The Antimicrobial Properties of Silver Nanoparticles in Bacillus subtilis Are Mediated by Released Ag+ Ions.* Plos One, 2015. **10**(12).

166. Hsueh, Y.-H., et al., *ZnO nanoparticles affect Bacillus subtilis cell growth and biofilm formation.* PloS one, 2015. **10**(6): p. e0128457.
167. Gitipour, A., et al., *Anaerobic toxicity of cationic silver nanoparticles.* Science of the Total Environment, 2016. **557**: p. 363-368.
168. Aminedi, R., et al., *Shape-dependent bactericidal activity of TiO2 for the killing of Gram-negative bacteria Agrobacterium tumefaciens under UV torch irradiation.* Environmental Science and Pollution Research, 2013. **20**(9): p. 6521-6530.
169. Sadiq, I.M., N. Chandrasekaran, and A. Mukherjee, *Studies on Effect of TiO2 Nanoparticles on Growth and Membrane Permeability of Escherichia coli, Pseudomonas aeruginosa, and Bacillus subtilis.* Current Nanoscience, 2010. **6**(4): p. 381-387.
170. Bhadra, P., et al., *Interaction of chitosan capped ZnO nanorods with Escherichia coli.* Materials Science & Engineering C-Materials for Biological Applications, 2011. **31**(5): p. 929-937.
171. Kumar, D., et al., *Qualitative toxicity assessment of silver nanoparticles on the fresh water bacterial isolates and consortium at low level of exposure concentration.* Ecotoxicology and Environmental Safety, 2014. **108**: p. 152-160.
172. Leung, Y.H., et al., *Antibacterial activity of ZnO nanoparticles with a modified surface under ambient illumination.* Nanotechnology, 2012. **23**(47).
173. Ramalingam, B., T. Parandhaman, and S.K. Das, *Antibacterial Effects of Biosynthesized Silver Nanoparticles on Surface Ultrastructure and Nanomechanical Properties of Gram-Negative Bacteria viz. Escherichia coli and Pseudomonas aeruginosa.* Acs Applied Materials & Interfaces, 2016. **8**(7): p. 4963-4976.
174. Dalai, S., et al., *A comparative cytotoxicity study of TiO2 nanoparticles under light and dark conditions at low exposure concentrations.* Toxicology Research, 2012. **1**(2): p. 116-130.
175. Cui, L., et al., *In Situ Study of the Antibacterial Activity and Mechanism of Action of Silver Nanoparticles by Surface-Enhanced Raman Spectroscopy.* Analytical Chemistry, 2013. **85**(11): p. 5436-5443.
176. Mirzajani, F., et al., *Antibacterial effect of silver nanoparticles on Staphylococcus aureus.* Research in Microbiology, 2011. **162**(5): p. 542-549.
177. Chatterjee, A.K., R. Chakraborty, and T. Basu, *Mechanism of antibacterial activity of copper nanoparticles.* Nanotechnology, 2014. **25**(13).
178. Giannousi, K., et al., *Hydrothermal synthesis of copper based nanoparticles: Antimicrobial screening and interaction with DNA.* Journal of Inorganic Biochemistry, 2014. **133**: p. 24-32.
179. Kumar, A., et al., *Engineered ZnO and TiO2 nanoparticles induce oxidative stress and DNA damage leading to reduced viability of Escherichia coli.* Free Radical Biology and Medicine, 2011. **51**(10): p. 1872-1881.
180. Chakraborty, R., et al., *A simple, fast and cost-effective method of synthesis of cupric oxide nanoparticle with promising antibacterial potency: Unraveling the biological and chemical modes of action.* Biochimica Et Biophysica Acta-General Subjects, 2015. **1850**(4): p. 845-856.
181. Liu, N., et al., *{101}-{001} Surface Heterojunction-Enhanced Antibacterial Activity of Titanium Dioxide Nanocrystals Under Sunlight Irradiation.* Acs Applied Materials & Interfaces, 2017. **9**(7): p. 5907-5915.

182. Quinteros, M.A., et al., *Oxidative stress generation of silver nanoparticles in three bacterial genera and its relationship with the antimicrobial activity.* Toxicology in Vitro, 2016. **36**: p. 216-223.
183. Subramaniyan, S.B., et al., *Evaluation of the toxicities of silver and silver sulfide nanoparticles against Gram-positive and Gram-negative bacteria.* Iet Nanobiotechnology, 2019. **13**(3): p. 326-331.
184. Swetha, S., et al., *Elucidation of Cell Killing Mechanism by Comparative Analysis of Photoreactions on Different Types of Bacteria.* Photochemistry and Photobiology, 2012. **88**(2): p. 414-422.
185. Dutta, R.K., B.P. Nenavathu, and M.K. Gangishetty, *Correlation between defects in capped ZnO nanoparticles and their antibacterial activity.* Journal of Photochemistry and Photobiology B-Biology, 2013. **126**: p. 105-111.
186. Lin, X.C., et al., *Toxicity of TiO2 Nanoparticles to Escherichia coli: Effects of Particle Size, Crystal Phase and Water Chemistry.* Plos One, 2014. **9**(10).
187. Chakraborti, S., et al., *The Molecular Basis of Inactivation of Metronidazole-Resistant Helicobacter pylori Using Polyethyleneimine Functionalized Zinc Oxide Nanoparticles.* Plos One, 2013. **8**(8).
188. Quinteros, M.A., et al., *Biosynthesized silver nanoparticles: Decoding their mechanism of action in Staphylococcus aureus and Escherichia coli.* International Journal of Biochemistry & Cell Biology, 2018. **104**: p. 87-93.
189. Kaweeteerawat, C., et al., *Cu Nanoparticles Have Different Impacts in Escherichia coli and Lactobacillus brevis than Their Microsized and Ionic Analogues.* Acs Nano, 2015. **9**(7): p. 7215-7225.
190. Mandal, D., et al., *Bio-fabricated silver nanoparticles preferentially targets Gram positive depending on cell surface charge.* Biomedicine & Pharmacotherapy, 2016. **83**: p. 548-558.
191. Zhang, Z.Z., et al., *Short-term impacts of Cu, CuO, ZnO and Ag nanoparticles (NPs) on anammox sludge: CuNPs make a difference.* Bioresource Technology, 2017. **235**: p. 281-291.
192. Liu, W., et al., *TiO2 nanoparticles alter iron homeostasis in Pseudomonas brassicacearum as revealed by PrrF sRNA modulation.* Environmental Science-Nano, 2016. **3**(6): p. 1473-1482.
193. Oliver, S., et al., *Enhancing the antimicrobial and antibiofilm effectiveness of silver nanoparticles prepared by green synthesis.* Journal of Materials Chemistry B, 2018. **6**(24): p. 4124-4138.
194. Dasgupta, N. and C. Ramalingam, *Silver nanoparticle antimicrobial activity explained by membrane rupture and reactive oxygen generation.* Environmental Chemistry Letters, 2016. **14**(4): p. 477-485.
195. Bala, N., et al., *Phenolic compound-mediated single-step fabrication of copper oxide nanoparticles for elucidating their influence on anti-bacterial and catalytic activity.* New Journal of Chemistry, 2017. **41**(11): p. 4458-4467.
196. Gopinath, V., et al., *In vitro toxicity, apoptosis and antimicrobial effects of phyto-mediated copper oxide nanoparticles.* RSC advances, 2016. **6**(112): p. 110986-110995.
197. Laha, D., et al., *Shape-dependent bactericidal activity of copper oxide nanoparticle mediated by DNA and membrane damage.* Materials Research Bulletin, 2014. **59**: p. 185-191.

198. Nair, S., et al., *Role of size scale of ZnO nanoparticles and microparticles on toxicity toward bacteria and osteoblast cancer cells.* Journal of Materials Science-Materials in Medicine, 2009. **20**: p. 235-241.
199. Okyay, T.O., et al., *Antibacterial properties and mechanisms of toxicity of sonochemically grown ZnO nanorods.* Rsc Advances, 2015. **5**(4): p. 2568-2575.
200. Raffi, M., et al., *Investigations into the antibacterial behavior of copper nanoparticles against Escherichia coli.* Annals of microbiology, 2010. **60**(1): p. 75-80.
201. Sarwar, S., et al., *The antimicrobial activity of ZnO nanoparticles against Vibrio cholerae: Variation in response depends on biotype.* Nanomedicine-Nanotechnology Biology and Medicine, 2016. **12**(6): p. 1499-1509.
202. Sonia, S., et al., *Synthesis of hierarchical CuO nanostructures: Biocompatible antibacterial agents for Gram-positive and Gram-negative bacteria.* Current Applied Physics, 2016. **16**(8): p. 914-921.
203. Wang, C., et al., *Antibacterial effects of zinc oxide nanoparticles on Escherichia coli K88.* African Journal of Biotechnology, 2012. **11**(44): p. 10248-10254.
204. Xie, Y., et al., *Antibacterial activity and mechanism of action of zinc oxide nanoparticles against Campylobacter jejuni.* Applied and environmental microbiology, 2011. **77**(7): p. 2325-2331.
205. Du, J., et al., *Antibacterial activity of a novel Forsythia suspensa fruit mediated green silver nanoparticles against food-borne pathogens and mechanisms investigation.* Materials Science & Engineering C-Materials for Biological Applications, 2019. **102**: p. 247-253.
206. Das, B., et al., *Green synthesized silver nanoparticles destroy multidrug resistant bacteria via reactive oxygen species mediated membrane damage.* Arabian Journal of Chemistry, 2017. **10**(6): p. 862-876.
207. Khan, S., et al., *Bacterial cellulose-titanium dioxide nanocomposites: nanostructural characteristics, antibacterial mechanism, and biocompatibility.* Cellulose, 2015. **22**(1): p. 565-579.
208. Kumar, V., et al., *Photoinduced green synthesis of silver nanoparticles using aqueous extract of Physalis angulata and its antibacterial and antioxidant activity.* Journal of Environmental Chemical Engineering, 2017. **5**(1): p. 744-756.
209. Lotha, R., et al., *Plant nutraceuticals (Quercetrin and Afzelin) capped silver nanoparticles exert potent antibiofilm effect against food borne pathogen Salmonella enterica serovar Typhi and curtail planktonic growth in zebrafish infection model.* Microbial Pathogenesis, 2018. **120**: p. 109-118.
210. Pan, S.F., et al., *Synthesis of Silver Nanoparticles Embedded Electrospun PAN Nanofiber Thin-Film Composite Forward Osmosis Membrane to Enhance Performance and Antimicrobial Activity.* Industrial & Engineering Chemistry Research, 2019. **58**(2): p. 984-993.
211. Ranjan, S. and C. Ramalingam, *Titanium dioxide nanoparticles induce bacterial membrane rupture by reactive oxygen species generation.* Environmental Chemistry Letters, 2016. **14**(4): p. 487-494.
212. Rauf, M.A., et al., *Biomimetically synthesized ZnO nanoparticles attain potent antibacterial activity against less susceptible S. aureus skin infection in experimental animals.* Rsc Advances, 2017. **7**(58): p. 36361-36373.

213. Shao, Y., et al., *Green synthesis of sodium alginate-silver nanoparticles and their antibacterial activity.* International Journal of Biological Macromolecules, 2018. **111**: p. 1281-1292.
214. Senthil, B., A. Rajasekar, and T. Devasena, *Mechanism of Bactericidal Action of Biosynthesized Silver Nanoparticles.* Research Journal of Biotechnology, 2018. **13**(1): p. 72-78.
215. Tamboli, D.P. and D.S. Lee, *Mechanistic antimicrobial approach of extracellularly synthesized silver nanoparticles against gram positive and gram negative bacteria.* Journal of Hazardous Materials, 2013. **260**: p. 878-884.
216. Tian, X., et al., *Bactericidal Effects of Silver Nanoparticles on Lactobacilli and the Underlying Mechanism.* Acs Applied Materials & Interfaces, 2018. **10**(10): p. 8443-8450.
217. Wang, Z.P., et al., *Anti-microbial activities of aerosolized transition metal oxide nanoparticles.* Chemosphere, 2010. **80**(5): p. 525-529.
218. Yi, J.L., et al., *Effect of polyhexamethylene biguanide functionalized silver nanoparticles on the growth of Staphylococcus aureus.* Fems Microbiology Letters, 2019. **366**(4).
219. Zhang, L.L., et al., *Investigation into the antibacterial behaviour of suspensions of ZnO nanoparticles (ZnO nanofluids).* Journal of Nanoparticle Research, 2007. **9**(3): p. 479-489.
220. Singh, A.V., et al., *Hydrophobic pinning with copper nanowhiskers leads to bactericidal properties.* Plos One, 2017. **12**(4).
221. Stefan, M., et al., *Enhanced antibacterial effect of silver nanoparticles obtained by electrochemical synthesis in poly(amide-hydroxyurethane) media.* Journal of Materials Science-Materials in Medicine, 2011. **22**(4): p. 789-796.
222. Syame, S.M., et al., *Synthesis of Copper-Chitosan Nanocomposites and their Applications in Treatment of Local Pathogenic Isolates Bacteria.* Oriental Journal of Chemistry, 2017. **33**(6): p. 2959-2969.
223. Yi, G.S., et al., *ZnO Nanopillar Coated Surfaces with Substrate-Dependent Superbactericidal Property.* Small, 2018. **14**(14).
224. Sinha, R., et al., *Interaction and nanotoxic effect of ZnO and Ag nanoparticles on mesophilic and halophilic bacterial cells.* Bioresource technology, 2011. **102**(2): p. 1516-1520.
225. Ahmed, B., et al., *ROS mediated destruction of cell membrane, growth and biofilms of human bacterial pathogens by stable metallic AgNPs functionalized from bell pepper extract and quercetin.* Advanced Powder Technology, 2018. **29**(7): p. 1601-1616.
226. Li, H.T., et al., *Transport, fate, and long-term impacts of metal oxide nanoparticles on the stability of an anaerobic methanogenic system with anaerobic granular sludge.* Bioresource Technology, 2017. **234**: p. 448-455.
227. Cervantes-Aviles, P. and G. Cuevas-Rodriguez, *Changes in nutrient removal and flocs characteristics generated by presence of ZnO nanoparticles in activated sludge process.* Chemosphere, 2017. **182**: p. 672-680.
228. Parveen, A., et al., *Emphasized Mechanistic Antimicrobial Study of Biofunctionalized Silver Nanoparticles on Model Proteus mirabilis.* Journal of Drug Delivery, 2018.
229. Alfaro-Gonzalez, B., et al., *Chitosan-silver nanoparticles as an approach to control bacterial proliferation, spores and antibiotic-resistant bacteria.* Biomedical Physics & Engineering Express, 2018. **4**(3).

230. Wang, D.L., et al., *Where does the toxicity of metal oxide nanoparticles come from: The nanoparticles, the ions, or a combination of both?* Journal of Hazardous Materials, 2016. **308**: p. 328-334.
231. Maillard, A., et al., *Studies on interaction of green silver nanoparticles with whole bacteria by surface characterization techniques.* Biochimica Et Biophysica Acta-Biomembranes, 2019. **1861**(6): p. 1086-1092.
232. Grigor'eva, A., et al., *Fine mechanisms of the interaction of silver nanoparticles with the cells of Salmonella typhimurium and Staphylococcus aureus.* Biometals, 2013. **26**(3): p. 479-488.
233. Brayner, R., et al., *Toxicological impact studies based on Escherichia coli bacteria in ultrafine ZnO nanoparticles colloidal medium.* Nano letters, 2006. **6**(4): p. 866-870.
234. Le, A.T., et al., *Synthesis of oleic acid-stabilized silver nanoparticles and analysis of their antibacterial activity.* Materials Science & Engineering C-Materials for Biological Applications, 2010. **30**(6): p. 910-916.
235. Tam, K.H., et al., *Antibacterial activity of ZnO nanorods prepared by a hydrothermal method.* Thin Solid Films, 2008. **516**(18): p. 6167-6174.
236. Sondi, I. and B. Salopek-Sondi, *Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria.* Journal of colloid and interface science, 2004. **275**(1): p. 177-182.
237. Baldi, F., et al., *Polysaccharide-based silver nanoparticles synthesized by Klebsiella oxytoca DSM 29614 cause DNA fragmentation in E-coli cells.* Biometals, 2016. **29**(2): p. 321-331.
238. Chen, J.N., et al., *Various antibacterial mechanisms of biosynthesized copper oxide nanoparticles against soilborne Ralstonia solanacearum.* Rsc Advances, 2019. **9**(7): p. 3788-3799.
239. Gallon, S.M.N., et al., *Characterization and study of the antibacterial mechanisms of silver nanoparticles prepared with microalgal exopolysaccharides.* Materials Science & Engineering C-Materials for Biological Applications, 2019. **99**: p. 685-695.
240. Hazarika, S.N., et al., *One-pot facile green synthesis of biocidal silver nanoparticles.* Materials Research Express, 2016. **3**(7).
241. Kumari, M., et al., *Enhanced Cellular Internalization: A Bactericidal Mechanism More Relative to Biogenic Nanoparticles than Chemical Counterparts.* Acs Applied Materials & Interfaces, 2017. **9**(5): p. 4519-4533.
242. Mirzajani, F., et al., *Effect of silver nanoparticles on Oryza sativa L. and its rhizosphere bacteria.* Ecotoxicology and Environmental Safety, 2013. **88**: p. 48-54.
243. Ni, Z.H., et al., *Synthesis of poly acrylic acid modified silver nanoparticles and their antimicrobial activities.* Materials Science & Engineering C-Materials for Biological Applications, 2014. **41**: p. 249-254.
244. Orou, S.F.C., et al., *Antibacterial activity by ZnO nanorods and ZnO nanodisks: A model used to illustrate "Nanotoxicity Threshold".* Journal of Industrial and Engineering Chemistry, 2018. **62**: p. 333-340.
245. Rastogi, L. and J. Arunachalam, *Synthesis and characterization of bovine serum albumin-copper nanocomposites for antibacterial applications.* Colloids and Surfaces B-Biointerfaces, 2013. **108**: p. 134-141.

246. Soman, S. and J.G. Ray, *Silver nanoparticles synthesized using aqueous leaf extract of Ziziphus oenoplia (L.) Mill: Characterization and assessment of antibacterial activity.* Journal of Photochemistry and Photobiology B-Biology, 2016. **163**: p. 391-402.
247. Thomas, R., et al., *Microbially and phytofabricated AgNPs with different mode of bactericidal action were identified to have comparable potential for surface fabrication of central venous catheters to combat Staphylococcus aureus biofilm.* Journal of Photochemistry and Photobiology B-Biology, 2017. **171**: p. 96-103.
248. Zhou, Y., et al., *Antibacterial activities of gold and silver nanoparticles against Escherichia coli and bacillus Calmette-Guerin.* Journal of Nanobiotechnology, 2012. **10**.
249. Espana-Sanchez, B.L., et al., *Early Stages of Antibacterial Damage of Metallic Nanoparticles by TEM and STEM-HAADF.* Current Nanoscience, 2018. **14**(1): p. 54-61.
250. Kim, S.W., Y.W. Baek, and Y.J. An, *Assay-dependent effect of silver nanoparticles to Escherichia coli and Bacillus subtilis.* Applied Microbiology and Biotechnology, 2011. **92**(5): p. 1045-1052.
251. Romero-Urbina, D.G., et al., *Ultrastructural changes in methicillin-resistant Staphylococcus aureus induced by positively charged silver nanoparticles.* Beilstein Journal of Nanotechnology, 2015. **6**: p. 2396-2405.
252. Siritongsuk, P., et al., *Two-Phase Bactericidal Mechanism of Silver Nanoparticles against Burkholderia pseudomallei.* Plos One, 2016. **11**(12).
253. Parashar, U.K., et al., *Study of mechanism of enhanced antibacterial activity by green synthesis of silver nanoparticles.* Nanotechnology, 2011. **22**(41).
254. Fang, F., et al., *A detailed approach to study the antibacterial mechanisms of nanostructure.* Applied Surface Science, 2012. **258**(10): p. 4397-4401.
255. Bera, R.K., S.M. Mandal, and C.R. Raj, *Antimicrobial activity of fluorescent Ag nanoparticles.* Letters in Applied Microbiology, 2014. **58**(6): p. 520-526.
256. Mathur, A., et al., *Decreased Phototoxic Effects of TiO2 Nanoparticles in Consortium of Bacterial Isolates from Domestic Waste Water.* Plos One, 2015. **10**(10).
257. Ravichandran, A., et al., *Phyto-mediated synthesis of silver nanoparticles using fucoidan isolated from Spatoglossum asperum and assessment of antibacterial activities.* Journal of Photochemistry and Photobiology B-Biology, 2018. **185**: p. 117-125.
258. McGivney, E., et al., *Disruption of Autolysis in Bacillus subtilis using TiO2 Nanoparticles.* Scientific Reports, 2017. **7**.
259. Ramani, M., et al., *Amino acid-mediated synthesis of zinc oxide nanostructures and evaluation of their facet-dependent antimicrobial activity.* Colloids and Surfaces B-Biointerfaces, 2014. **117**: p. 233-239.
260. Singh, M., et al., *Loss of outer membrane integrity in Gram-negative bacteria by silver nanoparticles loaded with Camellia sinensis leaf phytochemicals: plausible mechanism of bacterial cell disintegration.* Bulletin of Materials Science, 2016. **39**(7): p. 1871-1878.
261. Khan, A.U., et al., *Ultra-efficient photocatalytic deprivation of methylene blue and biological activities of biogenic silver nanoparticles.* Journal of Photochemistry and Photobiology B: Biology, 2016. **159**: p. 49-58.
262. Tiwari, V., et al., *Mechanism of Anti-bacterial Activity of Zinc Oxide Nanoparticle Against Carbapenem-Resistant Acinetobacter baumannii.* Frontiers in Microbiology, 2018. **9**.

263. Du, J., et al., *Biosynthesis of large-sized silver nanoparticles using Angelica keiskei extract and its antibacterial activity and mechanisms investigation.* Microchemical Journal, 2019. **147**: p. 333-338.
264. Varghese, R., et al., *Silver nanopaticles synthesized using the seed extract of Trigonella foenum-graecum L. and their antimicrobial mechanism and anticancer properties.* Saudi Journal of Biological Sciences, 2019. **26**(1): p. 148-154.
265. Venkatasubbu, G.D., et al., *Toxicity mechanism of titanium dioxide and zinc oxide nanoparticles against food pathogens.* Colloids and Surfaces B-Biointerfaces, 2016. **148**: p. 600-606.
266. Zhang, L.L., et al., *Diminished inhibitory impact of ZnO nanoparticles on anaerobic fermentation by the presence of TiO2 nanoparticles: Phenomenon and mechanism.* Science of the Total Environment, 2019. **647**: p. 313-322.
267. Qayyum, S. and A.U. Khan, *Biofabrication of broad range antibacterial and antibiofilm silver nanoparticles.* Iet Nanobiotechnology, 2016. **10**(5): p. 349-357.
268. Rajesh, S., V. Dharanishanthi, and A.V. Kanna, *Antibacterial mechanism of biogenic silver nanoparticles of Lactobacillus acidophilus.* Journal of Experimental Nanoscience, 2015. **10**(15): p. 1143-1152.
269. Rautela, A., J. Rani, and M. Debnath, *Green synthesis of silver nanoparticles from Tectona grandis seeds extract: characterization and mechanism of antimicrobial action on different microorganisms.* Journal of Analytical Science and Technology, 2019. **10**.
270. Cai, Q., et al., *Insight into Biological Effects of Zinc Oxide Nanoflowers on Bacteria: Why Morphology Matters.* Acs Applied Materials & Interfaces, 2016. **8**(16): p. 10109-10120.
271. Baek, S., et al., *Antibacterial effect and toxicity pathways of industrial and sunscreen ZnO nanoparticles on Escherichia coli.* Journal of Environmental Chemical Engineering, 2017. **5**(3): p. 3024-3032.
272. Baek, S., et al., *Effects of coating materials on antibacterial properties of industrial and sunscreen-derived titanium-dioxide nanoparticles on Escherichia coli.* Chemosphere, 2018. **208**: p. 196-206.
273. Jin, J.C., et al., *Ultrasmall silver nanoclusters: Highly efficient antibacterial activity and their mechanisms.* Biomaterials Science, 2017. **5**(2): p. 247-257.
274. Li, X.Z., et al., *Riboflavin-protected ultrasmall silver nanoclusters with enhanced antibacterial activity and the mechanisms.* Rsc Advances, 2019. **9**(23): p. 13275-13282.
275. Tripathy, N., et al., *Outstanding Antibiofilm Features of Quanta-CuO Film on Glass Surface.* Acs Applied Materials & Interfaces, 2016. **8**(24): p. 15128-15137.
276. Prasanna, V.L. and R. Vijayaraghavan, *Chemical manipulation of oxygen vacancy and antibacterial activity in ZnO.* Materials Science & Engineering C-Materials for Biological Applications, 2017. **77**: p. 1027-1034.
277. Fauss, E.K., et al., *Disinfection action of electrostatic versus steric-stabilized silver nanoparticles on E. coli under different water chemistries.* Colloids and Surfaces B-Biointerfaces, 2014. **113**: p. 77-84.
278. Liu, S.P., et al., *The influence of H2O2 on the antibacterial activity of ZnO.* Materials Research Express, 2019. **6**(8).
279. Jin, X., et al., *High-Throughput Screening of Silver Nanoparticle Stability and Bacterial Inactivation in Aquatic Media: Influence of Specific Ions.* Environmental Science & Technology, 2010. **44**(19): p. 7321-7328.

280. Kumar, S.S.D., et al., *Cellular imaging and bactericidal mechanism of green-synthesized silver nanoparticles against human pathogenic bacteria.* Journal of Photochemistry and Photobiology B-Biology, 2018. **178**: p. 259-269.
281. Bao, H.J., et al., *New Toxicity Mechanism of Silver Nanoparticles: Promoting Apoptosis and Inhibiting Proliferation.* Plos One, 2015. **10**(3).
282. Sotiriou, G.A. and S.E. Pratsinis, *Antibacterial activity of nanosilver ions and particles.* Environmental science & technology, 2010. **44**(14): p. 5649-5654.
283. Perelshtein, I., et al., *The influence of the crystalline nature of nano-metal oxides on their antibacterial and toxicity properties.* Nano Research, 2015. **8**(2): p. 695-707.
284. Ng, Y.H., et al., *Antibacterial activity of ZnO nanoparticles under ambient illumination - The effect of nanoparticle properties.* Thin Solid Films, 2013. **542**: p. 368-372.
285. Lopes, I., et al., *Toxicity and genotoxicity of organic and inorganic nanoparticles to the bacteria Vibrio fischeri and Salmonella typhimurium.* Ecotoxicology, 2012. **21**(3): p. 637-648.
286. Butler, K.S., et al., *Silver nanoparticles: correlating nanoparticle size and cellular uptake with genotoxicity.* Mutagenesis, 2015. **30**(4): p. 577-591.
287. Jomini, S., et al., *Modifications of the bacterial reverse mutation test reveals mutagenicity of TiO2 nanoparticles and byproducts from a sunscreen TiO2-based nanocomposite.* Toxicology Letters, 2012. **215**(1): p. 54-61.
288. Rudakiya, D.M. and K. Pawar, *Bactericidal potential of silver nanoparticles synthesized using cell-free extract of Comamonas acidovorans: in vitro and in silico approaches.* 3 Biotech, 2017. **7**.
289. Maillard, A., et al., *Interaction of green silver nanoparticles with model membranes: possible role in the antibacterial activity.* Colloids and Surfaces B-Biointerfaces, 2018. **171**: p. 320-326.
290. Tamayo, L.A., et al., *Release of silver and copper nanoparticles from polyethylene nanocomposites and their penetration into Listeria monocytogenes.* Materials Science & Engineering C-Materials for Biological Applications, 2014. **40**: p. 24-31.
291. Amato, E., et al., *Synthesis, Characterization and Antibacterial Activity against Gram Positive and Gram Negative Bacteria of Biomimetically Coated Silver Nanoparticles.* Langmuir, 2011. **27**(15): p. 9165-9173.
292. Ananth, A., et al., *Soft jet plasma-assisted synthesis of Zinc oxide nanomaterials: Morphology controls and antibacterial activity of ZnO.* Chemical Engineering Journal, 2017. **322**: p. 742-751.
293. Cheon, J.Y., et al., *Shape-dependent antimicrobial activities of silver nanoparticles.* International Journal of Nanomedicine, 2019. **14**: p. 2773-2780.
294. de Lucas-Gil, E., et al., *The fight against multidrug-resistant organisms: The role of ZnO crystalline defects.* Materials Science & Engineering C-Materials for Biological Applications, 2019. **99**: p. 575-581.
295. de Lucas-Gil, E., et al., *ZnO Nanoporous Spheres with Broad-Spectrum Antimicrobial Activity by Physicochemical Interactions.* Acs Applied Nano Materials, 2018. **1**(7): p. 3214-3225.
296. Kim, H.R., et al., *Direct synthesis of magnetron sputtered nanostructured Cu films with desired properties via plasma chemistry for their efficient antibacterial application.* Plasma Processes and Polymers, 2018. **15**(9).

297. Li, M., L.Z. Zhu, and D.H. Lin, *Toxicity of ZnO Nanoparticles to Escherichia coli: Mechanism and the Influence of Medium Components.* Environmental Science & Technology, 2011. **45**(5): p. 1977-1983.
298. Li, M.H., et al., *Stability, Bioavailability, and Bacterial Toxicity of ZnO and Iron-Doped ZnO Nanoparticles in Aquatic Media.* Environmental Science & Technology, 2011. **45**(2): p. 755-761.
299. Naqvi, Q.U., et al., *Size-dependent inhibition of bacterial growth by chemically engineered spherical ZnO nanoparticles.* Journal of Biological Physics, 2019. **45**(2): p. 147-159.
300. Yang, T., et al., *Tuning crystallization and morphology of zinc oxide with polyvinylpyrrolidone: Formation mechanisms and antimicrobial activity.* Journal of Colloid and Interface Science, 2019. **546**: p. 43-52.
301. Wang, Q.W., et al., *Facet- dependent generation of superoxide radical anions by ZnO nanomaterials under simulated solar light.* Environmental Science-Nano, 2018. **5**(12): p. 2864-2875.
302. Sharma, R.K., M. Agarwal, and K. Balani, *Effect of ZnO morphology on affecting bactericidal property of ultra high molecular weight polyethylene biocomposite.* Materials Science & Engineering C-Materials for Biological Applications, 2016. **62**: p. 843-851.
303. Tien, D.C., et al., *Colloidal silver fabrication using the spark discharge system and its antimicrobial effect on Staphylococcus aureus.* Medical Engineering & Physics, 2008. **30**(8): p. 948-952.
304. Wu, Y.P., et al., *A facile method to prepare size-tunable silver nanoparticles and its antibacterial mechanism.* Advanced Powder Technology, 2018. **29**(2): p. 407-415.
305. Anthony, K.J.P., M. Murugan, and S. Gurunathan, *Biosynthesis of silver nanoparticles from the culture supernatant of Bacillus marisflavi and their potential antibacterial activity.* Journal of Industrial and Engineering Chemistry, 2014. **20**(4): p. 1505-1510.
306. Sharma, R., et al., *Aspect-ratio-dependent photoinduced antimicrobial and photocatalytic organic pollutant degradation efficiency of ZnO nanorods.* Research on Chemical Intermediates, 2017. **43**(10): p. 5345-5364.
307. Prokhorov, E., et al., *Chitosan/copper nanocomposites: Correlation between electrical and antibacterial properties.* Colloids and Surfaces B-Biointerfaces, 2019. **180**: p. 186-192.
308. Ramani, M., S. Ponnusamy, and C. Muthamizhchelvan, *Preliminary investigations on the antibacterial activity of zinc oxide nanostructures.* Journal of Nanoparticle Research, 2013. **15**(4).
309. Ann, L.C., et al., *Antibacterial responses of zinc oxide structures against Staphylococcus aureus, Pseudomonas aeruginosa and Streptococcus pyogenes.* Ceramics International, 2014. **40**(2): p. 2993-3001.
310. Xu, X.L., et al., *Antimicrobial Mechanism Based on H2O2 Generation at Oxygen Vacancies in ZnO Crystals.* Langmuir, 2013. **29**(18): p. 5573-5580.
311. Lakshmi Prasanna, V. and R. Vijayaraghavan, *Insight into the mechanism of antibacterial activity of ZnO: surface defects mediated reactive oxygen species even in the dark.* Langmuir, 2015. **31**(33): p. 9155-9162.

312. Ramani, M., S. Ponnusamy, and C. Muthamizhchelvan, *From zinc oxide nanoparticles to microflowers: A study of growth kinetics and biocidal activity.* Materials Science & Engineering C-Materials for Biological Applications, 2012. **32**(8): p. 2381-2389.
313. Espinosa-Cristóbal, L.F., et al., *Antimicrobial sensibility of Streptococcus mutans serotypes to silver nanoparticles.* Materials Science and Engineering: C, 2012. **32**(4): p. 896-901.
314. Kanwal, A., et al., *Size-dependent inhibition of bacterial growth by chemically engineered spherical ZnO nanoparticles.* Journal of biological physics, 2019. **45**(2): p. 147-159.
315. Wani, I.A., et al., *Structural characterization and antimicrobial properties of silver nanoparticles prepared by inverse microemulsion method.* Colloids and Surfaces B: Biointerfaces, 2013. **101**: p. 243-250.
316. Batista, C.C.S., et al., *Antimicrobial activity of nano-sized silver colloids stabilized by nitrogen-containing polymers: the key influence of the polymer capping.* Rsc Advances, 2018. **8**(20): p. 10873-10882.
317. Kora, A.J. and J. Arunachalam, *Assessment of antibacterial activity of silver nanoparticles on Pseudomonas aeruginosa and its mechanism of action.* World Journal of Microbiology & Biotechnology, 2011. **27**(5): p. 1209-1216.
318. Stabryla, L.M., et al., *Emerging investigator series: it's not all about the ion: support for particle-specific contributions to silver nanoparticle antimicrobial activity.* Environmental Science-Nano, 2018. **5**(9): p. 2047-2068.
319. Imlay, J.A., *Diagnosing oxidative stress in bacteria: not as easy as you might think.* Current opinion in microbiology, 2015. **24**: p. 124-131.
320. Gu, M.B. and S.H. Choi, *Monitoring and classification of toxicity using recombinant bioluminescent bacteria.* Water Science and Technology, 2001. **43**(2): p. 147-154.
321. Podila, R., et al., *Illuminating nano-bio interactions: A spectroscopic perspective.* Mrs Bulletin, 2014. **39**(11): p. 990-995.
322. Lowe, R., et al., *Transcriptomics technologies.* PLOS Computational Biology, 2017. **13**(5): p. e1005457.
323. Jones, C.F. and D.W. Grainger, *In vitro assessments of nanomaterial toxicity.* Adv Drug Deliv Rev, 2009. **61**(6): p. 438-56.
324. Hu, X.J., et al., *Synchrotron FTIR spectroscopy reveals molecular changes in Escherichia coli upon Cu2+ exposure.* Nuclear Science and Techniques, 2016. **27**(3).
325. Ivask, A., et al., *Methodologies and approaches for the analysis of cell-nanoparticle interactions.* Wiley Interdiscip Rev Nanomed Nanobiotechnol, 2018. **10**(3): p. e1486.
326. Leung, Y.H., et al., *Transmission electron microscopy artifacts in characterization of the nanomaterial-cell interactions.* Applied Microbiology and Biotechnology, 2017. **101**(13): p. 5469-5479.
327. Chen, S., et al., *Avoiding artefacts during electron microscopy of silver nanomaterials exposed to biological environments.* Journal of Microscopy, 2016. **261**(2): p. 157-166.
328. Wang, C.Z., C.J. Ehrhardt, and V.K. Yadavalli, *Nanoscale imaging and hydrophobicity mapping of the antimicrobial effect of copper on bacterial surfaces.* Micron, 2016. **88**: p. 16-23.
329. Septiadi, D., et al., *Nanoparticle-Cell Interaction: A Cell Mechanics Perspective.* Advanced Materials, 2018. **30**(19).

330. Vranic, S., et al., *Deciphering the mechanisms of cellular uptake of engineered nanoparticles by accurate evaluation of internalization using imaging flow cytometry.* Particle and Fibre Toxicology, 2013. **10**.
331. Vásquez-Vivar, J., et al., *[18] Electron spin resonance spin-trapping detection of superoxide generated by neuronal nitric oxide synthase*, in *Methods in Enzymology*. 1999, Academic Press. p. 169-177.
332. Oh, S.J., et al., *Incompatibility of silver nanoparticles with lactate dehydrogenase leakage assay for cellular viability test is attributed to protein binding and reactive oxygen species generation.* Toxicology Letters, 2014. **225**(3): p. 422-432.
333. Damoiseaux, R., et al., *No time to lose—high throughput screening to assess nanomaterial safety.* Nanoscale, 2011. **3**(4).
334. Najim, N.A., *Comparative Study of Different Methods to Determine the Role of Reactive Oxygen Species Induced by Zinc Oxide Nanoparticles.* Aro-the Scientific Journal of Koya University, 2015. **3**(2): p. 30-34.
335. Kalyanaraman, B., et al., *Measuring reactive oxygen and nitrogen species with fluorescent probes: challenges and limitations.* Free Radic Biol Med, 2012. **52**(1): p. 1-6.
336. Dasgupta, N., et al., *Thermal co-reduction approach to vary size of silver nanoparticle: its microbial and cellular toxicology.* Environmental Science and Pollution Research, 2016. **23**(5): p. 4149-4163.
337. Elespuru, R., et al., *Genotoxicity Assessment of Nanomaterials: Recommendations on Best Practices, Assays, and Methods.* Toxicological Sciences, 2018. **164**(2): p. 391-416.
338. Pasquet, J., et al., *Antimicrobial activity of zinc oxide particles on five micro-organisms of the Challenge Tests related to their physicochemical properties.* International Journal of Pharmaceutics, 2014. **460**(1-2): p. 92-100.
339. Maurer-Jones, M.A., et al., *Characterization of silver ion dissolution from silver nanoparticles using fluorous-phase ion-selective electrodes and assessment of resultant toxicity to Shewanella oneidensis.* Chemical Science, 2013. **4**(6): p. 2564-2572.
340. Zhang, J., et al., *The effects and the potential mechanism of environmental transformation of metal nanoparticles on their toxicity in organisms.* Environmental Science: Nano, 2018. **5**(11): p. 2482-2499.
341. Freitas, D.N., et al., *Beyond the passive interactions at the nano-bio interface: evidence of Cu metalloprotein-driven oxidative dissolution of silver nanoparticles.* Journal of Nanobiotechnology, 2016. **14**.
342. Kakinen, A., et al., *The Effect of Composition of Different Ecotoxicological Test Media on Free and Bioavailable Copper from CuSO4 and CuO Nanoparticles: Comparative Evidence from a Cu-Selective Electrode and a Cu-Biosensor.* Sensors, 2011. **11**(11): p. 10502-10521.
343. Kim, D.P., et al., *High cell density attenuates reactive oxygen species: Implications for in vitro assays.* Wound Repair and Regeneration, 2012. **20**(1): p. 74-82.