Tallinna Tehnikaülikool

Energiatehnoloogia Instituut

Termoelektrilised termomeetrid

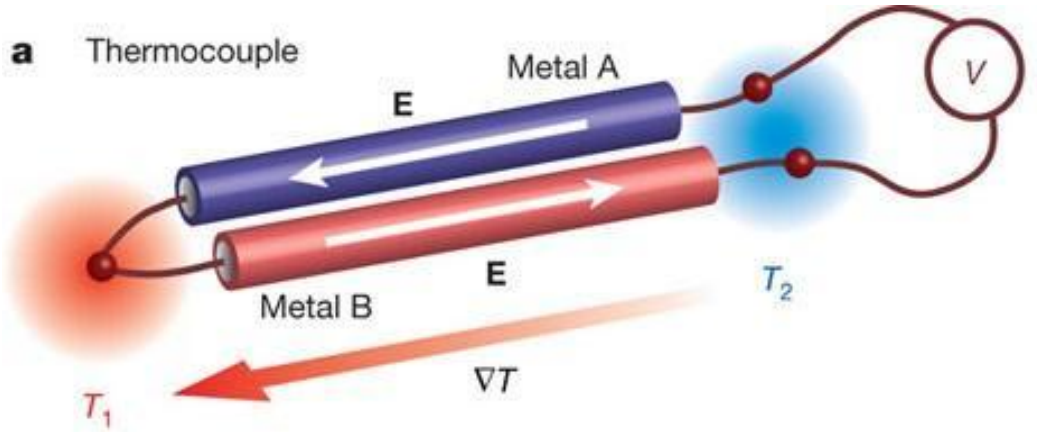
Töö põhimõte. Materjalid. Külmjootekoha temperatuuriparand.

Õppeaine kood: MSJ0001

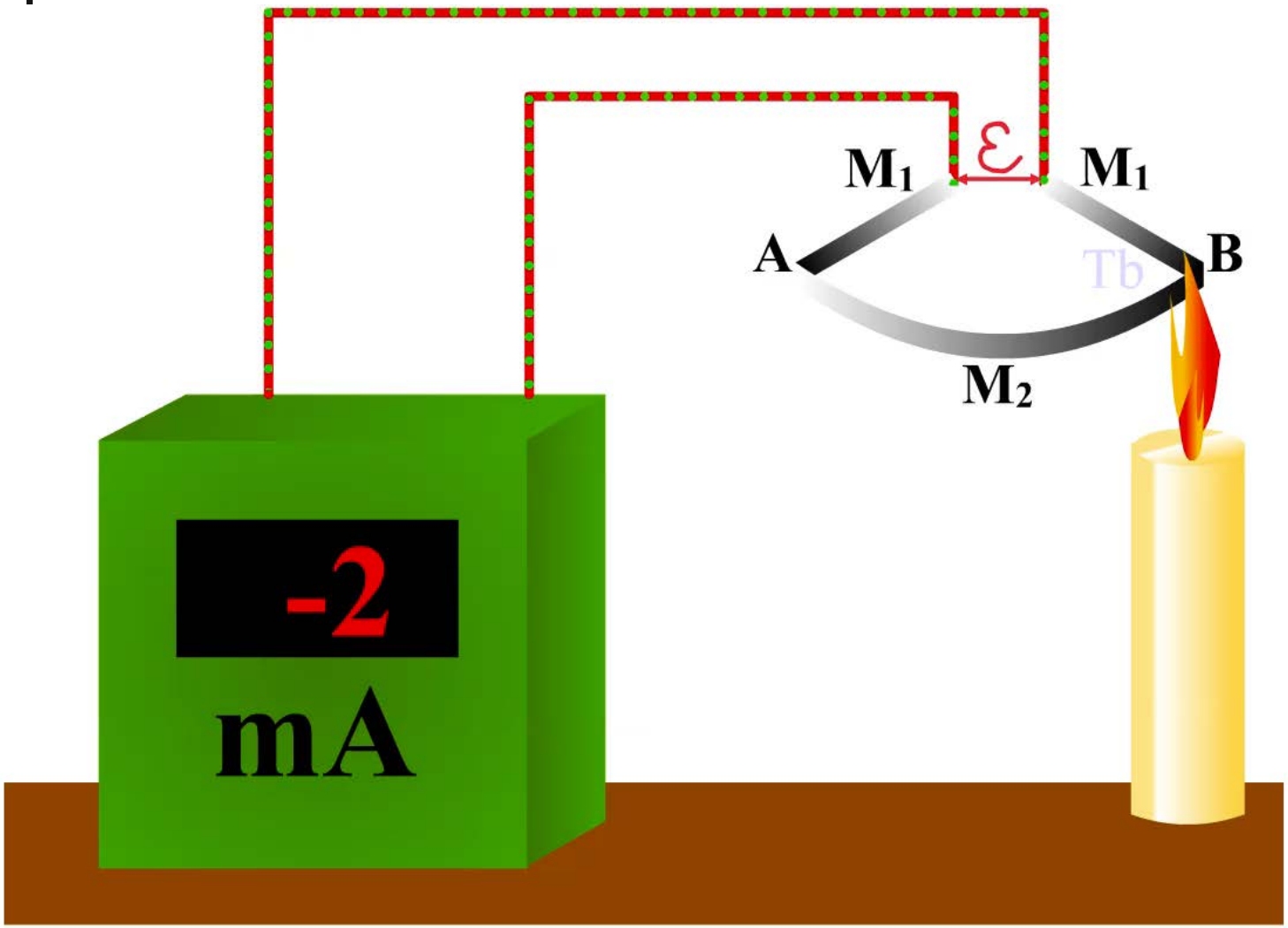
Õppejõud: Andrei Dedov

Termopaaride töö põhimõte

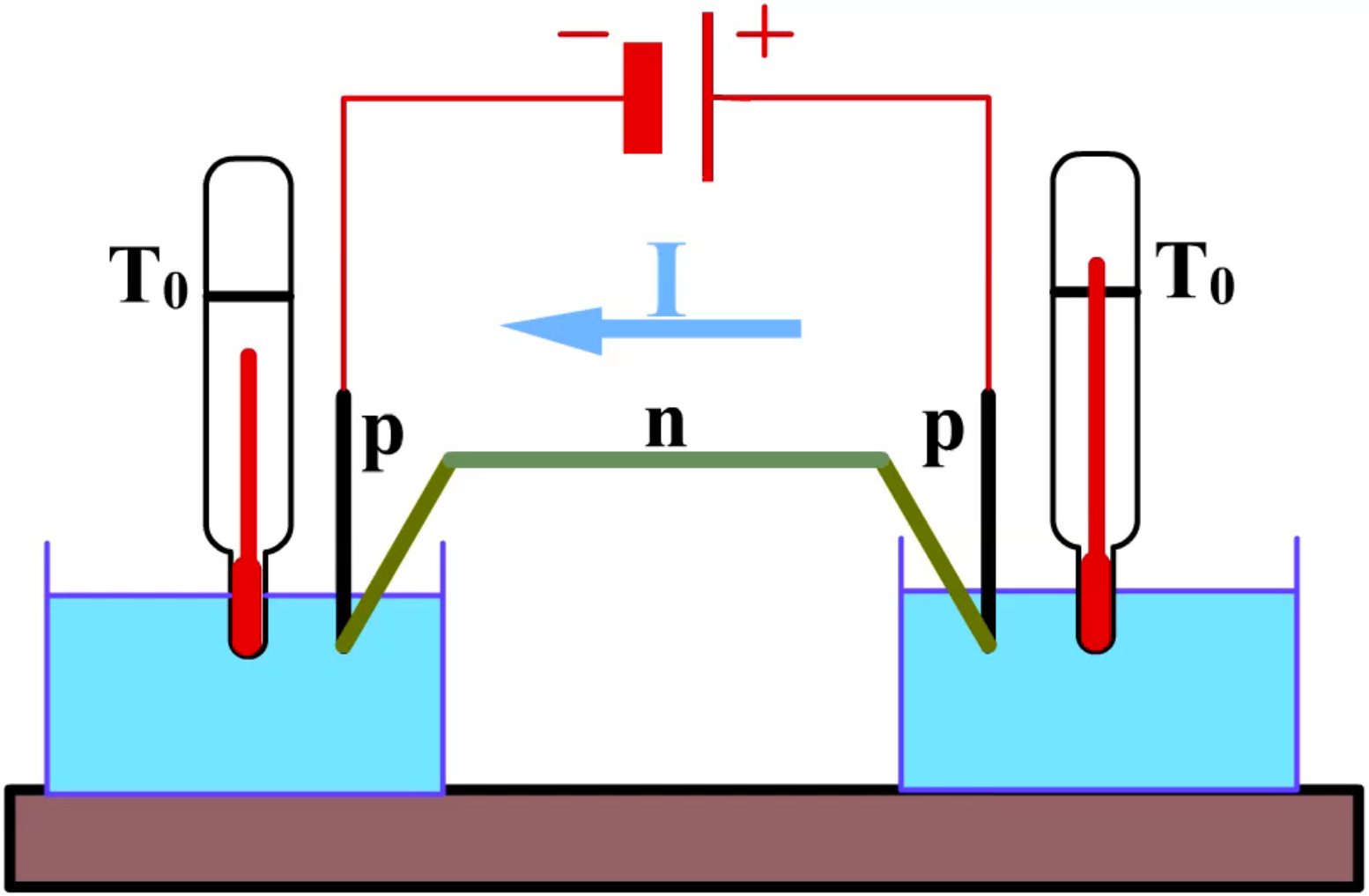
Termopaaride töö põhineb termoelektrilisel ehk Seebecki efektil, mis seisneb järgnevas. Kui võtta kaks erinevast materjalist elektrijuhti, need kokku joota ja jootekohta kuumutada, siis tekib jootekohas elektromotoorjõud (nn termoelektromotoorjõud), mille suurus sõltub nii kasutatud materjalidest kui ka jootekoha temperatuurist.



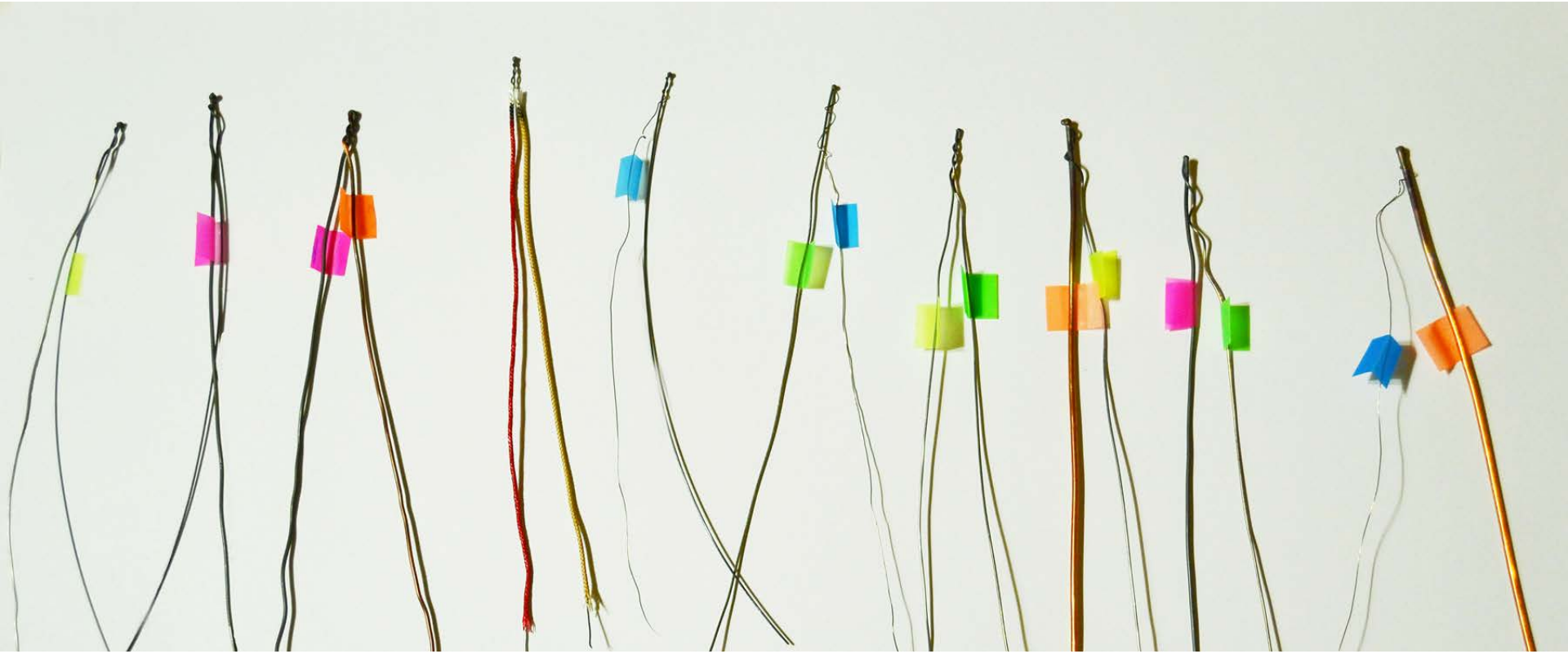
Seebecki efekt



Peltier’ efekt



Termopaar



Termopaaride materjalid

Termopaaride termoelektroodideks kasutatavad materjalid peavad vastama järgnevatele nõuetele:

- Materjalipaar peab tagama võimalikult suure ja stabiilse termoelektromotoorjõu.
- Kasutatavad materjalid peavad olema head elektrijuhid.
- Kasutatavad materjalid peavad olema stabiilsed, s.t. termoelektriliste ja füüsiliste omaduste muutumatus materjalide pikaajalisel kasutamisel. Materjalide stabiilsus võimaldab üheselt gradueerida termopaari ja termo-emj mõõteriista otseselt temperatuurikraadides.
- Kasutatavate materjalide tootmisviis peab tagama materjalide püsivaid omadusi.
- Kasutatava materjalipaari termo-emj sõltuvust temperatuurist peab olema võimalikult lähedane lineaarsele.
- Kasutatavad materjalid ei tohi olla liialt kallid.

Termopaaride materjalid

Termopaare valmistatakse metallidest ja nende sulamitest. Termoelektroodidena kasutatakse järgmisi sulameid:

- Kromell - nikli ja kroomi sulam (90,5%Ni + 9,5%Cr);
- Alumel - nikli alusel sulam (94,5%Ni + 5,5%(Al, Mn, Si, Co));
- Kopell - vase ja nikli sulam (56%Cu + 44%Ni);
- Konstantaan - vase ja nikli sulam (60%Cu + 40%Ni)

Materjalid	Tüübi tähis	Võimalik mõõdetava temperatuuri vahemik (°C)	Maksimaalne temperatuur lühiajalisel kasutamisel (°C)	Termoemj. keskmised väärtused (μV/K)	Gradueering
Cu-CuNi	T	–250… 400	600	23…69	EN 60 584-1[5]
Fe-CuNi	J	–200… 700	900	34…69	EN 60 584-1
NiCr-CuNi	E	–200… 700	1000	40...80	EN 60 584-1
NiCr-NiAl	K	–200…1000	1300	41…36	EN 60 584-1
NiCrSi-NiSi	N	0…1000	1300	41…36	EN 60 584-1
PtRh10-Pt	S	0…1300	1600	6…12	EN 60 584-1
PtRh13-Pt	R	0…1300	1600	5…14	EN 60 584-1
PtRh30-PtRh6	B	0…1600	1800	0…11	EN 60 584-1
Cu-CuNi	U	–250...400	600	19…70	DIN 43710
Fe-CuNi	L	–200...700	900	30…70	DIN 43710

ANSI Code	ANSI MC 96.1 Colour Coding		Alloy Combination		Comments Environment Bare Wire	Maximum T/C Grade Temp. Range	EMF (mV) Over Max. Temp. Range	IEC 584-3 Colour Coding		IEC Code
	Thermocouple Grade	Extension Grade	+ Lead	– Lead				Thermocouple Grade	Intrinsically Safe	
J			IRON Fe (magnetic)	CONSTANTAN COPPER-NICKEL Cu-Ni	Reducing, Vacuum, Inert. Limited Use in Oxidising at High Temperatures. Not Recommended for Low Temperatures.	–210 to 1200°C –346 to 2193°F	–8.095 to 69.553			J
K			CHROME NICKEL-CHROMIUM Ni-Cr	NICKEL-ALUMINUM Ni-Al (magnetic)	Clean Oxidising and Inert. Limited Use in Vacuum or Reducing. Wide Temperature Range, Most Popular Calibration	–270 to 1372°C –454 to 2501°F	–6.458 to 54.886			K
T			COPPER Cu	CONSTANTAN COPPER-NICKEL Cu–Ni	Mild Oxidising, Reducing Vacuum or Inert. Good Where Moisture Is Present. Low Temperature & Cryogenic Applications	–270 to 400°C –454 to 752°F	–6.258 to 20.872			T
E			CHROME NICKEL-CHROMIUM Ni-Cr	CONSTANTAN COPPER-NICKEL Cu-Ni	Oxidising or Inert. Limited Use in Vacuum or Reducing. Highest EMF Change Per Degree	–270 to 1000°C –454 to 1832°F	–9.835 to 76.373			E
N			NICROSIL Ni-Cr-Si	NISIL Ni-Si-Mg	Alternative to Type K. More Stable at High Temps	–270 to 1300°C –450 to 2372°F	–4.345 to 47.513			N
R	NONE ESTABLISHED		PLATINUM-13% RHODIUM Pt-13% Rh	PLATINUM Pt	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.226 to 21.101			R
S	NONE ESTABLISHED		PLATINUM-10% RHODIUM Pt-10% Rh	PLATINUM Pt	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.236 to 18.693			S
U	NONE ESTABLISHED		COPPER Cu	COPPER-LOW NICKEL Cu-Ni	Extension Grade Connecting Wire for R & S Thermocouples, Also Known as RX & SX Extension Wire.					U
B	NONE ESTABLISHED		PLATINUM-30% RHODIUM Pt-30% Rh	PLATINUM-6% RHODIUM Pt-6% Rh	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temp. Common Use in Glass Industry	0 to 1820°C 32 to 3308°F	0 to 13.820			B
G* (W)	NONE ESTABLISHED		TUNGSTEN W	TUNGSTEN-26% RHENIUM W-26% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F). Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 38.564	NO STANDARD USE ANSI COLOUR CODE		G (W)
C* (W5)	NONE ESTABLISHED		TUNGSTEN-5% RHENIUM W-5% Re	TUNGSTEN-26% RHENIUM W-26% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F) Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 37.066	NO STANDARD USE ANSI COLOUR CODE		C (W5)
D* (W3)	NONE ESTABLISHED		TUNGSTEN-3% RHENIUM W-3% Re	TUNGSTEN-25% RHENIUM W-25% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F)–Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 39.506	NO STANDARD USE ANSI COLOUR CODE		D (W3)

Termo-emj sõltuvus temperatuurist

Termopaari gradueerimistabel

MAXIMUM TEMPERATURE RANGE

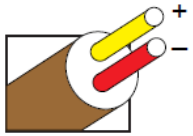
Thermocouple Grade
– 328 to 2282°F
– 200 to 1250°C

Extension Grade
32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
Special: 1.1°C or 0.4%

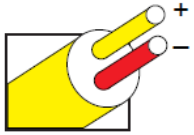
COMMENTS, BARE WIRE ENVIRONMENT:
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C



Thermocouple Grade

Nickel-Chromium vs. Nickel-Aluminum



Extension Grade

Revised Thermocouple Reference Tables

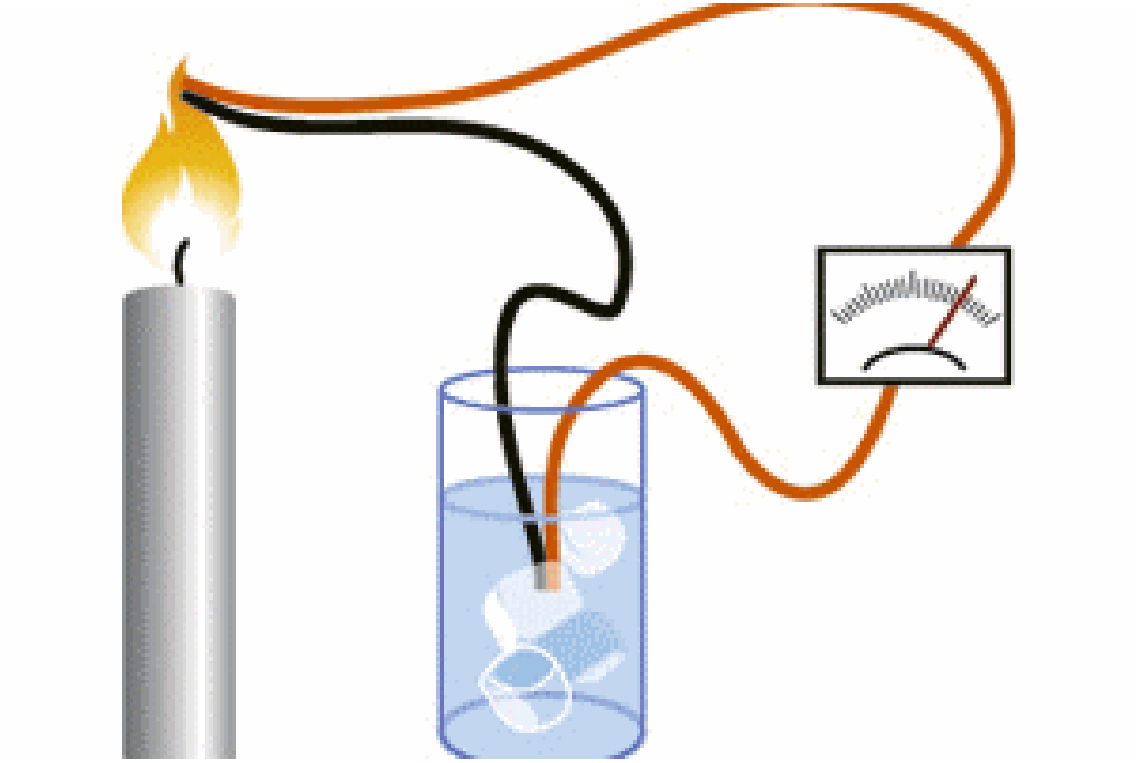
TYPE K
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

Thermoelectric Voltage in Millivolts

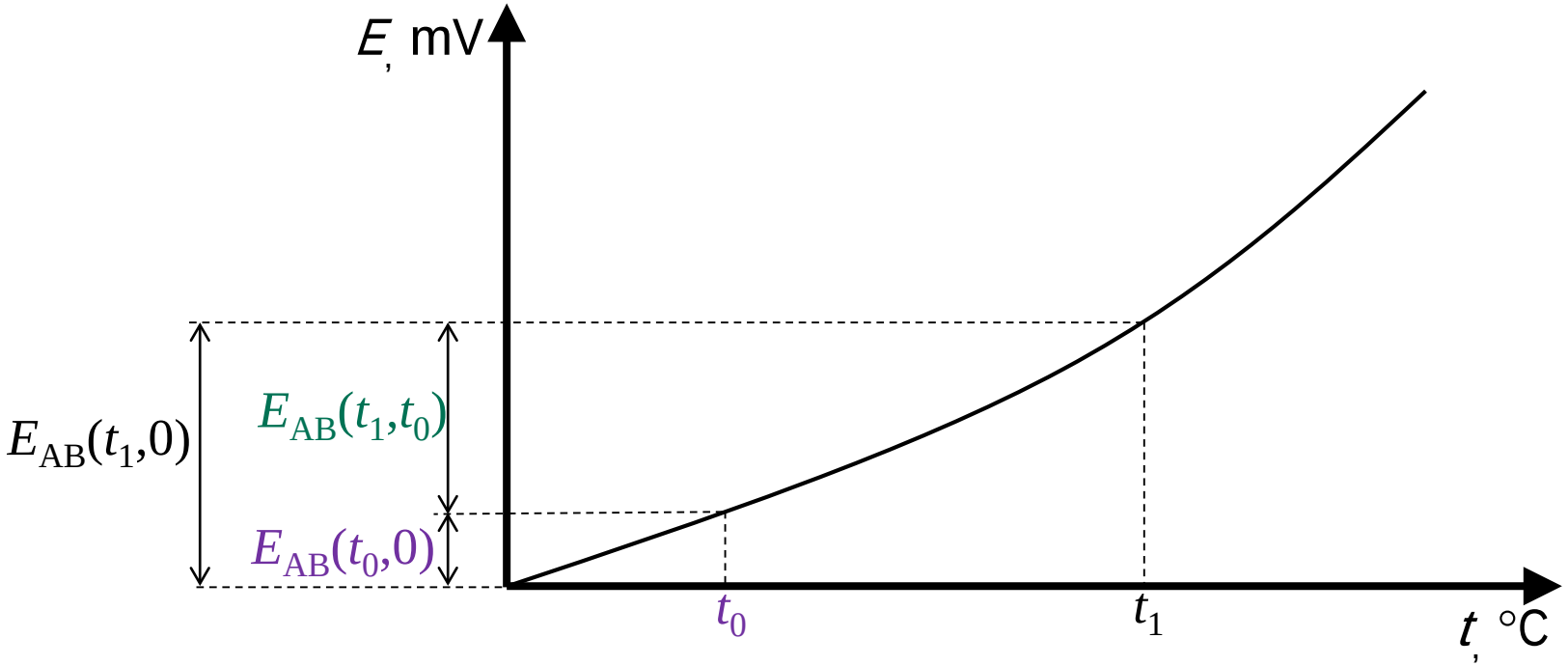
°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-260
-250	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-250
-240	-6.404	-6.399	-6.393	-6.388	-6.382	-6.377	-6.370	-6.364	-6.358	-6.351	-6.344	-240
-230	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-230
-220	-6.262	-6.252	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-220
-210	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-210
-200	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-200
-190	-5.891	-5.876	-5.861	-5.845	-5.829	-5.813	-5.797	-5.780	-5.763	-5.747	-5.730	-190
-180	-5.730	-5.713	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.588	-5.569	-5.550	-180
-170	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.435	-5.415	-5.395	-5.374	-5.354	-170
-160	-5.354	-5.333	-5.313	-5.292	-5.271	-5.250	-5.228	-5.207	-5.185	-5.163	-5.141	-160
-150	-5.141	-5.119	-5.097	-5.074	-5.052	-5.029	-5.006	-4.983	-4.960	-4.936	-4.913	-150
-140	-4.913	-4.889	-4.865	-4.841	-4.817	-4.793	-4.768	-4.744	-4.719	-4.694	-4.669	-140
-130	-4.669	-4.644	-4.618	-4.593	-4.567	-4.542	-4.516	-4.490	-4.463	-4.437	-4.411	-130
-120	-4.411	-4.384	-4.357	-4.330	-4.303	-4.276	-4.249	-4.221	-4.194	-4.166	-4.138	-120
-110	-4.138	-4.110	-4.082	-4.054	-4.025	-3.997	-3.968	-3.939	-3.911	-3.882	-3.852	-110
-100	-3.852	-3.823	-3.794	-3.764	-3.734	-3.705	-3.675	-3.645	-3.614	-3.584	-3.554	-100
-90	-3.554	-3.523	-3.492	-3.462	-3.431	-3.400	-3.368	-3.337	-3.306	-3.274	-3.243	-90
-80	-3.243	-3.211	-3.179	-3.147	-3.115	-3.083	-3.050	-3.018	-2.986	-2.953	-2.920	-80
-70	-2.920	-2.887	-2.854	-2.821	-2.788	-2.755	-2.721	-2.688	-2.654	-2.620	-2.587	-70
-60	-2.587	-2.553	-2.519	-2.485	-2.450	-2.416	-2.382	-2.347	-2.312	-2.278	-2.243	-60
-50	-2.243	-2.208	-2.173	-2.138	-2.103	-2.067	-2.032	-1.996	-1.961	-1.925	-1.889	-50
-40	-1.889	-1.854	-1.818	-1.782	-1.745	-1.709	-1.673	-1.637	-1.600	-1.564	-1.527	-40
-30	-1.527	-1.490	-1.453	-1.417	-1.380	-1.343	-1.305	-1.268	-1.231	-1.194	-1.156	-30
-20	-1.156	-1.119	-1.081	-1.043	-1.006	-0.968	-0.930	-0.892	-0.854	-0.816	-0.778	-20
-10	-0.778	-0.739	-0.701	-0.663	-0.624	-0.586	-0.547	-0.508	-0.470	-0.431	-0.392	-10
0	-0.392	-0.353	-0.314	-0.275	-0.236	-0.197	-0.157	-0.118	-0.079	-0.039	0.000	0

°C	0	1	2	3	4	5	6	7	8	9	10	°C
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091	430
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516	440
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	18.941	450
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	19.366	460
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	19.792	470
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	20.218	480
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	20.644	490
500	20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028	21.071	500
510	21.071	21.113	21.156	21.199	21.241	21.284	21.326	21.369	21.412	21.454	21.497	510
520	21.497	21.540	21.582	21.625	21.668	21.710	21.753	21.796	21.838	21.881	21.924	520
530	21.924	21.966	22.009	22.052	22.094	22.137	22.179	22.222	22.265	22.307	22.350	530
540	22.350	22.393	22.435	22.478	22.521	22.563	22.606	22.649	22.691	22.734	22.776	540

Külmjootekoha temperatuuriparand



Külmjootekoha temperatuuriparand

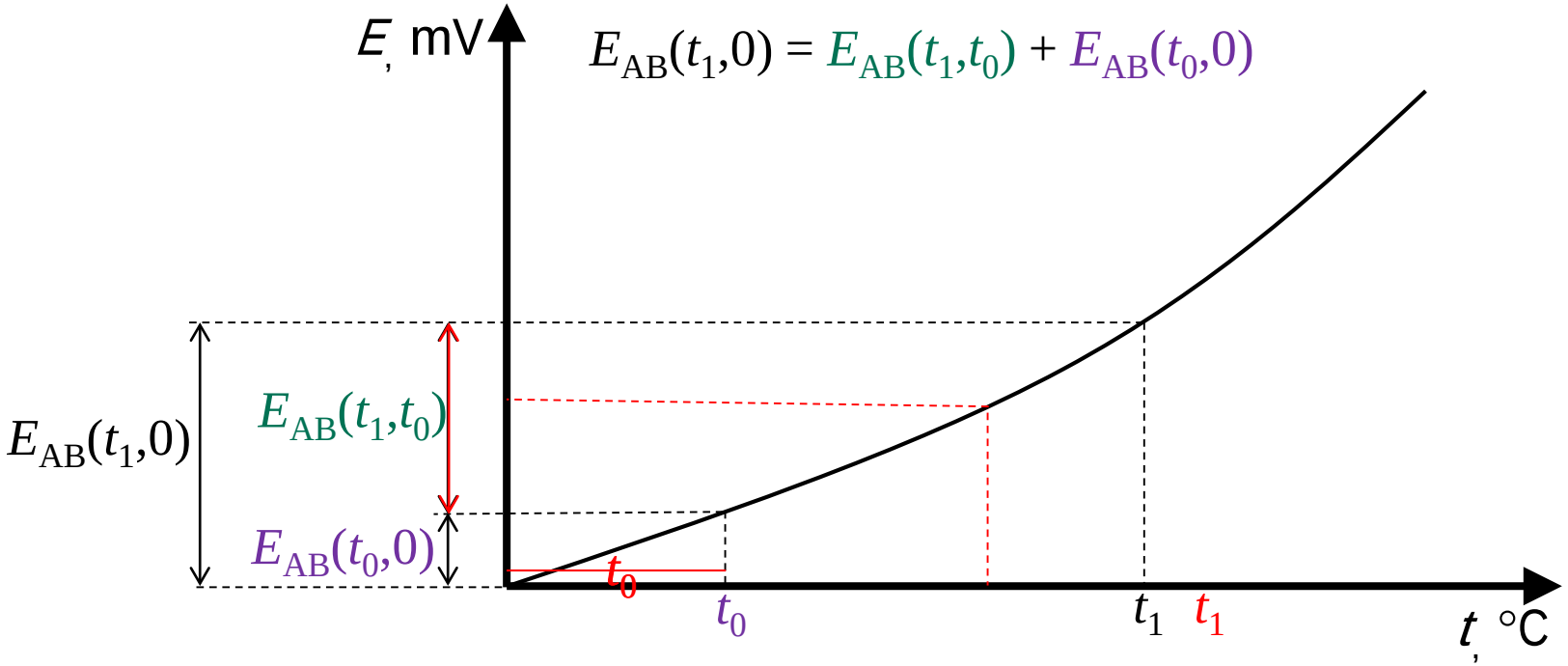


$$E_{AB}(t_1,0) = E_{AB}(t_1,t_0) + E_{AB}(t_0,0)$$

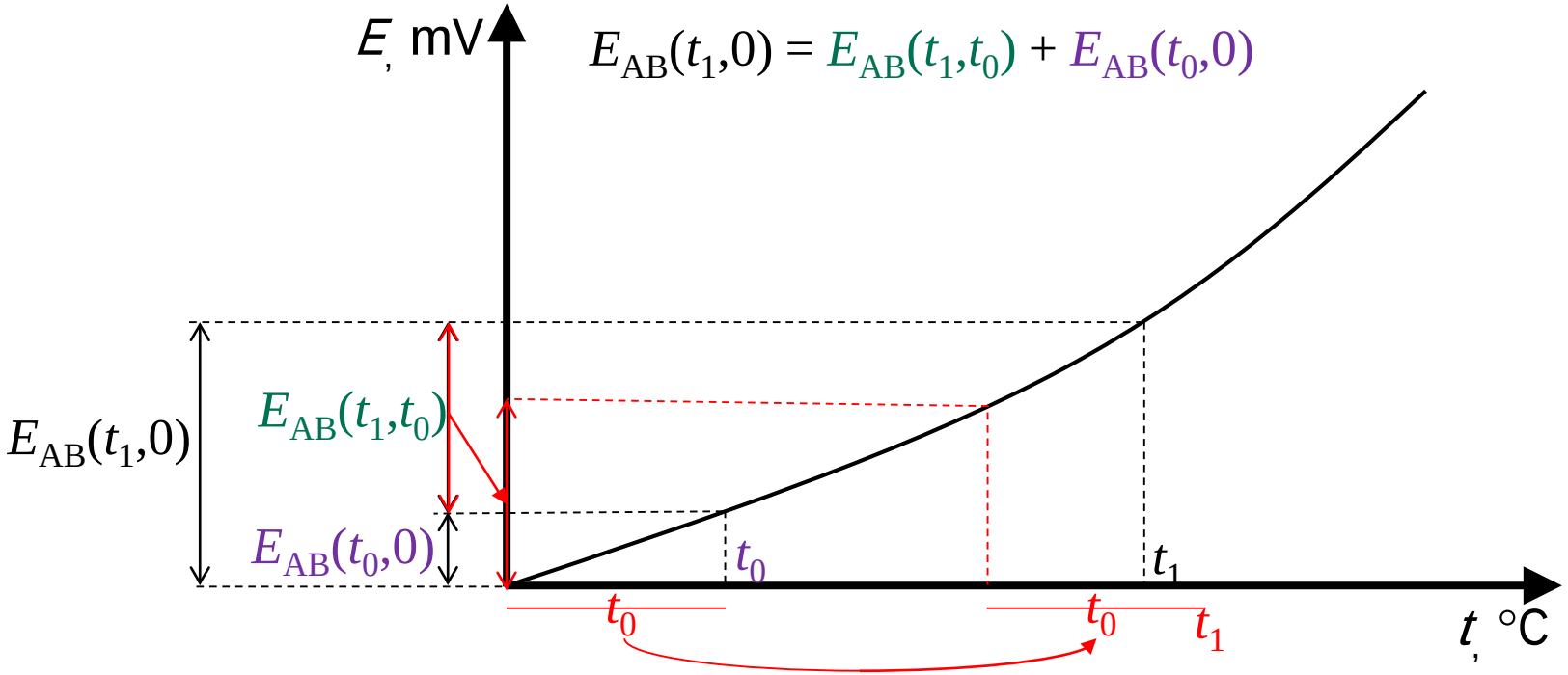
Näitab (mV)

Külmjootekoha temperatuuriparand

Külmjootekoha temperatuuriparand



Külmjootekoha temperatuuriparand



Õige

$t_0 \Longrightarrow E_{AB}(t_0,0)$

$E_{AB}(t_1,t_0) + E_{AB}(t_0,0) = E_{AB}(t_1,0)$

$E_{AB}(t_1,0) \Longrightarrow t_1$

Vale

$E_{AB}(t_1,t_0) \Longrightarrow t$

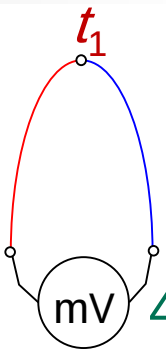
$t + t_0 = t_1$

Gradueerimistabeli kasutamine

1. Fikseeri termopaari näit (E_{mv}, mV), külmliite temperatuur (t_0,°C) ja tee kindlaks termopaari tüüp;
2. Leia termopaari gradueerimistabel („thermocouple type X table“, mõni juhend materjal vms.);
3. Tabelist leia külmliidese temperatuurile (t_0) vastav termopinge (E_0);
4. Summeeri külm- ja kuumliite termopinged ($E = E_0 + E_{mv}$);
5. Leia tabelist termopingele (E) vastav temperatuur.

Gradueerimistabeli kasutamine

TYPE S
Reference Tables
N.I.S.T.
Monograph 175
Revised to ITS-90



t_0 = 20 °C
4,17 mV

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050	0.055	0
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107	0.113	10
20	0.113	0.119	0.125	0.131	0.137	0.143	0.149	0.155	0.161	0.167	0.173	20
30	0.173	0.179	0.185	0.191	0.197	0.204	0.210	0.216	0.222	0.229	0.235	30
40	0.235	0.241	0.248	0.254	0.260	0.267	0.273	0.280	0.286	0.292	0.299	40
450	3.742	3.752	3.762	3.771	3.781	3.791	3.801	3.810	3.820	3.830	3.840	450
460	3.840	3.850	3.859	3.869	3.879	3.889	3.898	3.908	3.918	3.928	3.938	460
470	3.938	3.947	3.957	3.967	3.977	3.987	3.997	4.006	4.016	4.026	4.036	470
480	4.036	4.046	4.056	4.065	4.075	4.085	4.095	4.105	4.115	4.125	4.134	480
490	4.134	4.144	4.154	4.164	4.174	4.184	4.194	4.204	4.213	4.223	4.233	490
500	4.233	4.243	4.253	4.263	4.273	4.283	4.293	4.303	4.313	4.323	4.332	500
510	4.332	4.342	4.352	4.362	4.372	4.382	4.392	4.402	4.412	4.422	4.432	510
520	4.432	4.442	4.452	4.462	4.472	4.482	4.492	4.502	4.512	4.522	4.532	520
530	4.532	4.542	4.552	4.562	4.572	4.582	4.592	4.602	4.612	4.622	4.632	530
540	4.632	4.642	4.652	4.662	4.672	4.682	4.692	4.702	4.712	4.722	4.732	540
°C	0	1	2	3	4	5	6	7	8	9	10	°C

https://www.omega.com/techref/pdf/z208-209.pdf

$E_{AB}(t_1,t_0)$ = 4,17 mV

$E_{AB}(t_0,0)$ = 0,113 mV

$E_{AB}(t_1,0) = E_{AB}(t_1,t_0) + E_{AB}(t_0,0)$

$E_{AB}(t_1,0)$ = 4,17 + 0,113 =
= 4,283 mV

t_1 = 505 °C

Gradueerimistabeli kasutamine

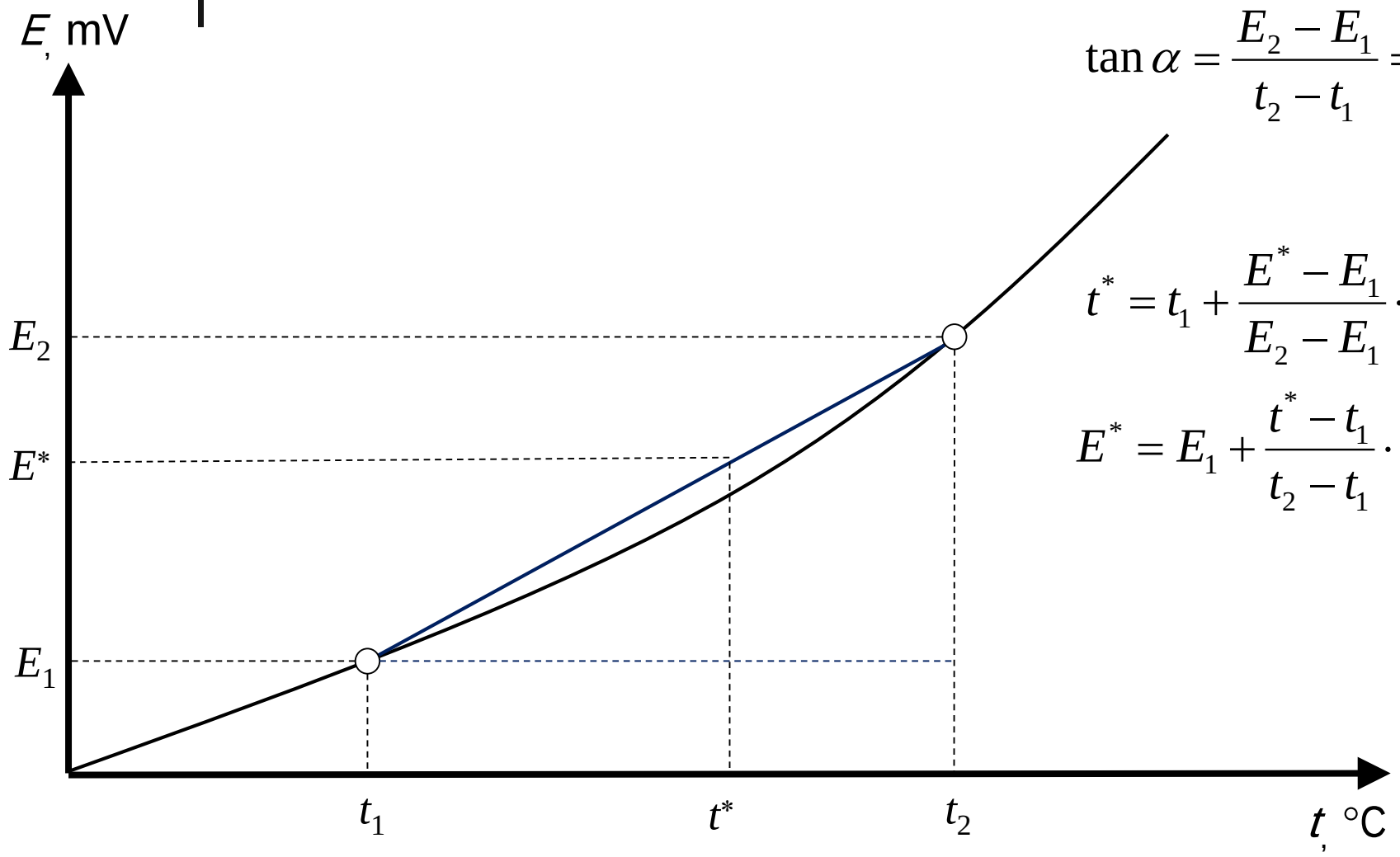
Külmliite temp, t_0, °C	Termopinge, E_{mV}, mV
15	2,462
24	4,693
28	5,016

Külmliite termo-pinge, E_0, mV	Termopinge, $E_0 + E_{mV}$, mV	Temperatuur, t, °C
0,597	3,059	75
0,960	5,653	138
1,122	6,138	150

TYPE K
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140

Interpoleerimine



$$\tan\alpha = \frac{E_2 - E_1}{t_2 - t_1} = \frac{E^* - E_1}{t^* - t_1}$$

$$t^* = t_1 + \frac{E^* - E_1}{E_2 - E_1} \cdot (t_2 - t_1)$$

$$E^* = E_1 + \frac{t^* - t_1}{t_2 - t_1} \cdot (E_2 - E_1)$$

Külmjootekoha temperatuuriparand

$t^* = 24{,}2\ °C \qquad E^* = ?$

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050	0.055	0
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107	0.113	10
20	0.113	0.119	0.125	0.131	0.137	0.143	0.149	0.155	0.161	0.167	0.173	20
30	0.173	0.179	0.185	0.191	0.197	0.204	0.210	0.216	0.222	0.229	0.235	30
40	0.235	0.241	0.248	0.254	0.260	0.267	0.273	0.280	0.286	0.292	0.299	40

TYPE S
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

$$E^* = 0{,}137 + E_x$$

$$E_x\ \text{mV} \rightarrow (24{,}2 - 24)\ °C$$
$$(0{,}143 - 0{,}137)\ \text{mV} \rightarrow (25 - 24)\ °C$$

$$E^* = 0{,}137 + \frac{24{,}2 - 24}{25 - 24} \cdot (0{,}143 - 0{,}137) = 0{,}1382 \quad \text{mV}$$

$$E^* = E_1 + \frac{t^* - t_1}{t_2 - t_1} \cdot (E_2 - E_1)$$

Külmjootekoha temperatuuriparand

$E^* = 4{,}275$ mV $\qquad t^* = ?$

°C	0	1	2	3	4	5	6	7	8	9	10	°C
500	4.233	4.243	4.253	4.263	4.273	4.283	4.293	4.303	4.313	4.323	4.332	500
510	4.332	4.342	4.352	4.362	4.372	4.382	4.392	4.402	4.412	4.422	4.432	510
520	4.432	4.442	4.452	4.462	4.472	4.482	4.492	4.502	4.512	4.522	4.532	520
530	4.532	4.542	4.552	4.562	4.572	4.582	4.592	4.602	4.612	4.622	4.632	530
540	4.632	4.642	4.652	4.662	4.672	4.682	4.692	4.702	4.712	4.722	4.732	540

TYPE S
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

$$t^* = 504 + t_x$$

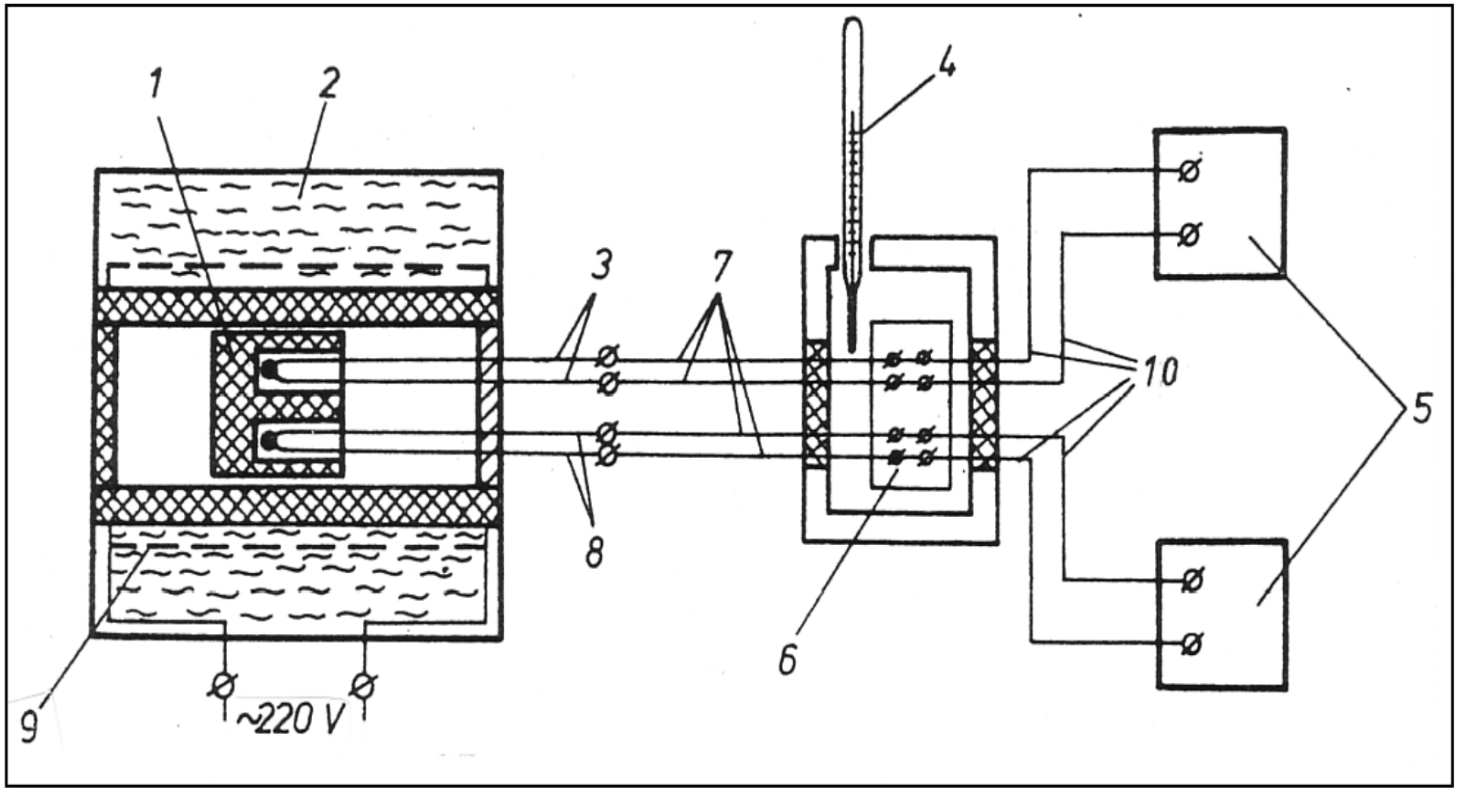
$$t_x\ °\text{C} \rightarrow (4{,}275 - 4{,}273)\ \text{mV}$$

$$(505 - 504)\ °\text{C} \rightarrow (4{,}283 - 4{,}273)\ \text{mV}$$

$$t^* = 504 + \frac{4{,}275 - 4{,}273}{4{,}283 - 4{,}273} \cdot (505 - 504) = 504{,}2\ \ °\text{C}$$

$$t^* = t_1 + \frac{E^* - E_1}{E_2 - E_1} \cdot (t_2 - t_1)$$

Laboratoorne töö nr.1



Laboratoorne töö nr.1

	Võrdlustermopaar (gr.S)			Kalibr. termopaar (gr.K)			Külmliide temperatuur			Abs. Viga	
								Parand			
	Lugem **E'**	Tegelik termoemj **E = E' + ΔE**	Temperatuur **t**	Lugem **E'$_1$**	Tegelik termoemj **E$_1$ = E' + ΔE$_1$**	Temperatuur **t$_1$**	Temperatuur t$_{kl}$	**gr.S ΔE**	**gr.K ΔE$_1$**	**Δ = t - t$_1$**	**ΔE$_{mV}$ = E$_0$ - E$_1$**
nr.	mV	mV	°C	mV	mV	°C	°C	mV	mV	°C	mV
1	**1.328**	**1.441**	**200**	**7.36**	**8.158**	**200.5**	**20**	**0.113**	**0.798**	**-0.5**	**-0.02**
2											
3											

E$_0$ – termopaari (gr.K) termoemj temperatuuril **t**

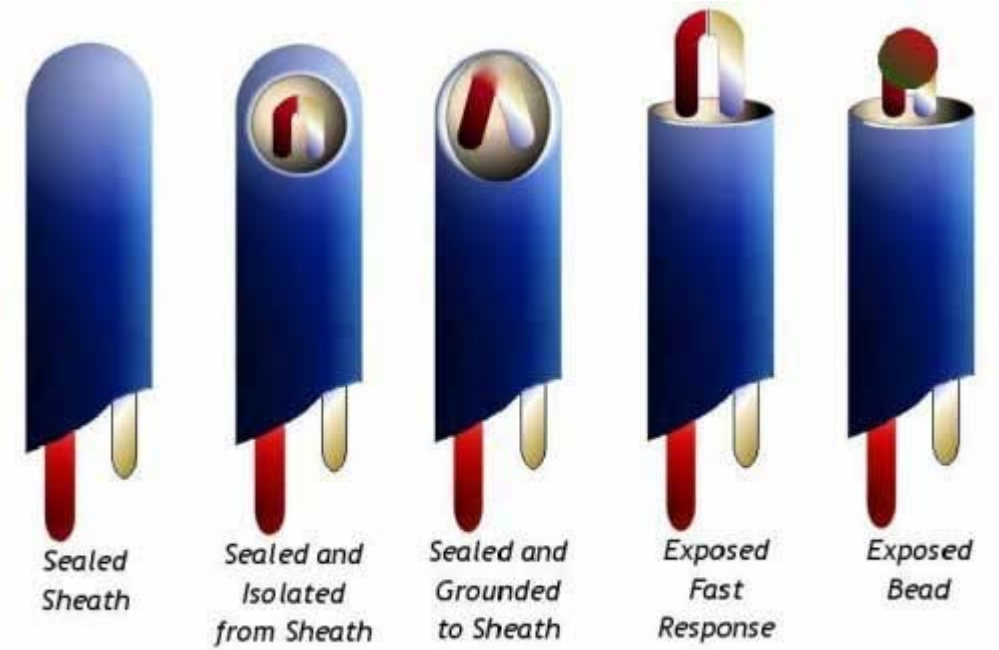
Handheld termopaarid

Külmjootekoha temperatuuriparand

Termopaari külmjootekoha temperatuuriparandi automaatse sisseviimise skeem

Termopaaride patarei

Termopaari tööjootekohad

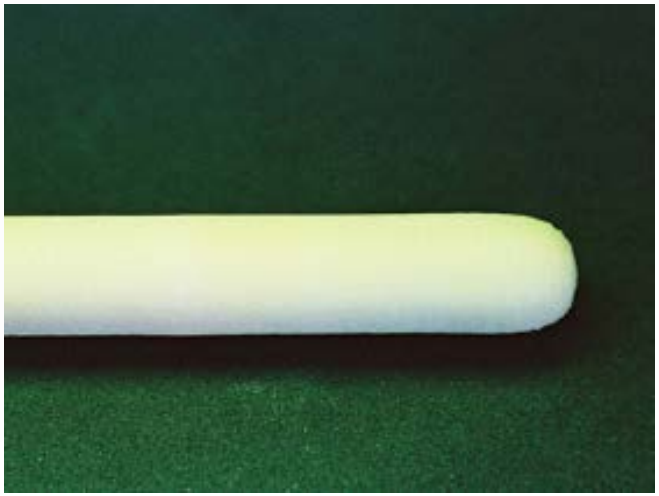


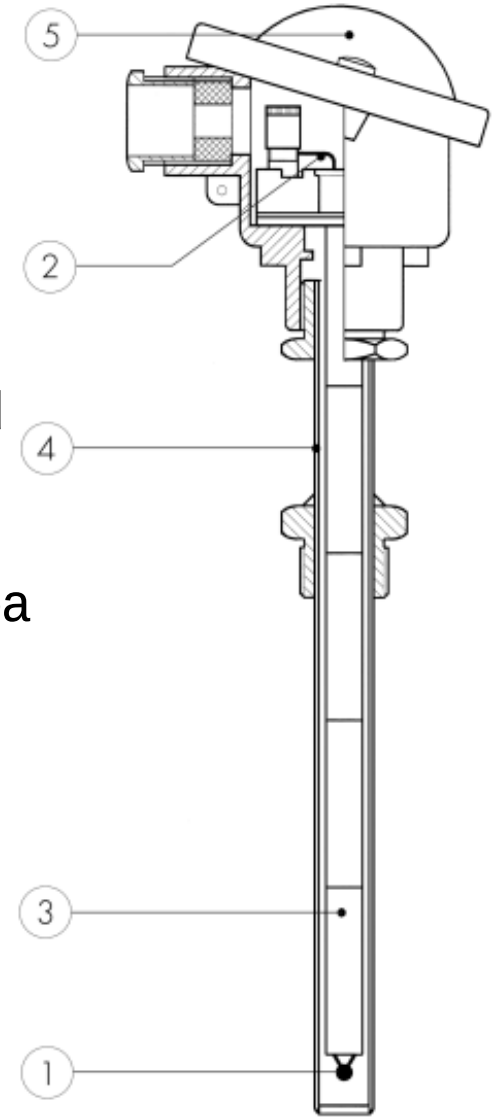
Thermocouple Sheath Options

Termopaari konstruktsioon

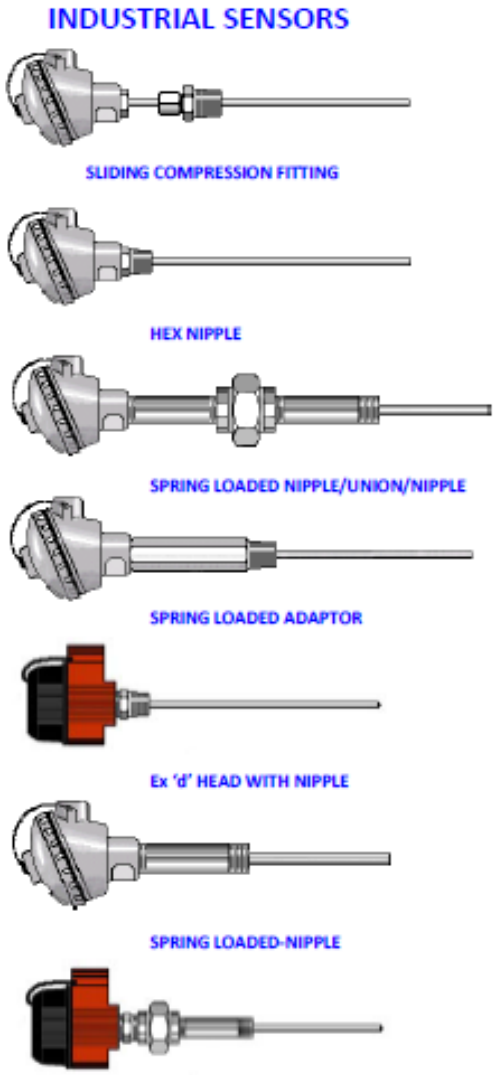
Selleks, et vältida termopaari termoelektroodide purunemist ja kahjustamist mõõdetava agressiivse keskkonna poolt, on vaja termopaari tööjootekoht paigutada kaitsekesta.

1 – tööjootekoht
2 – termoelektrood
3 – isolatsioon
4 – kaitsetoru
5 – termopaari kaba





Tööstuslikud termopaarid



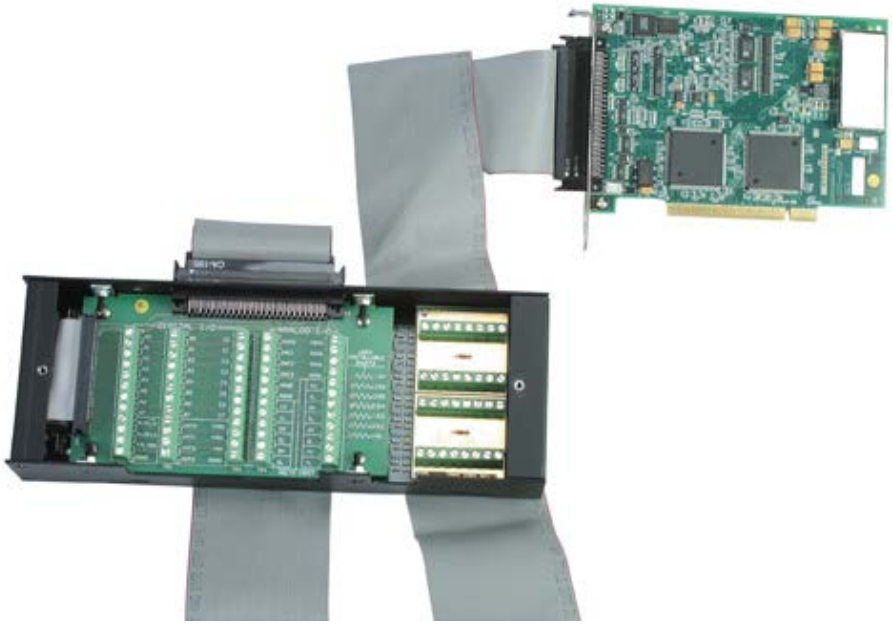
Normeerivad muundurid

Muundurite ülesanded:

- **Elektromagneetiliste häirete vähendamine;**
- Anduri nõrga signaali võimendamine;
- Anduri karakteristiku lineariseerimine;
- Võrdlusjootekoha temperatuuri kompenseerimine (termopaar);
- Mõõteriistade nomenklatuuri vähendamine.

Universaalsed mõõteriistad

Arvutite kasutamine *t*-mõõtmisel



Plug-in kaart

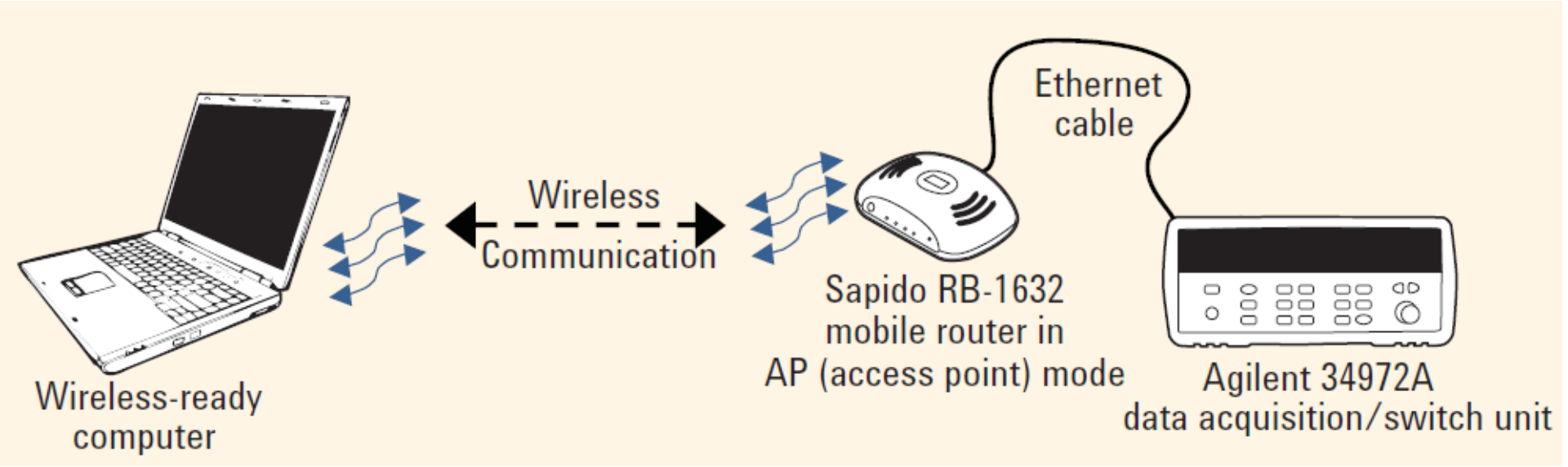
Sisendmoodul

Andmete edastamine (*wireless*)

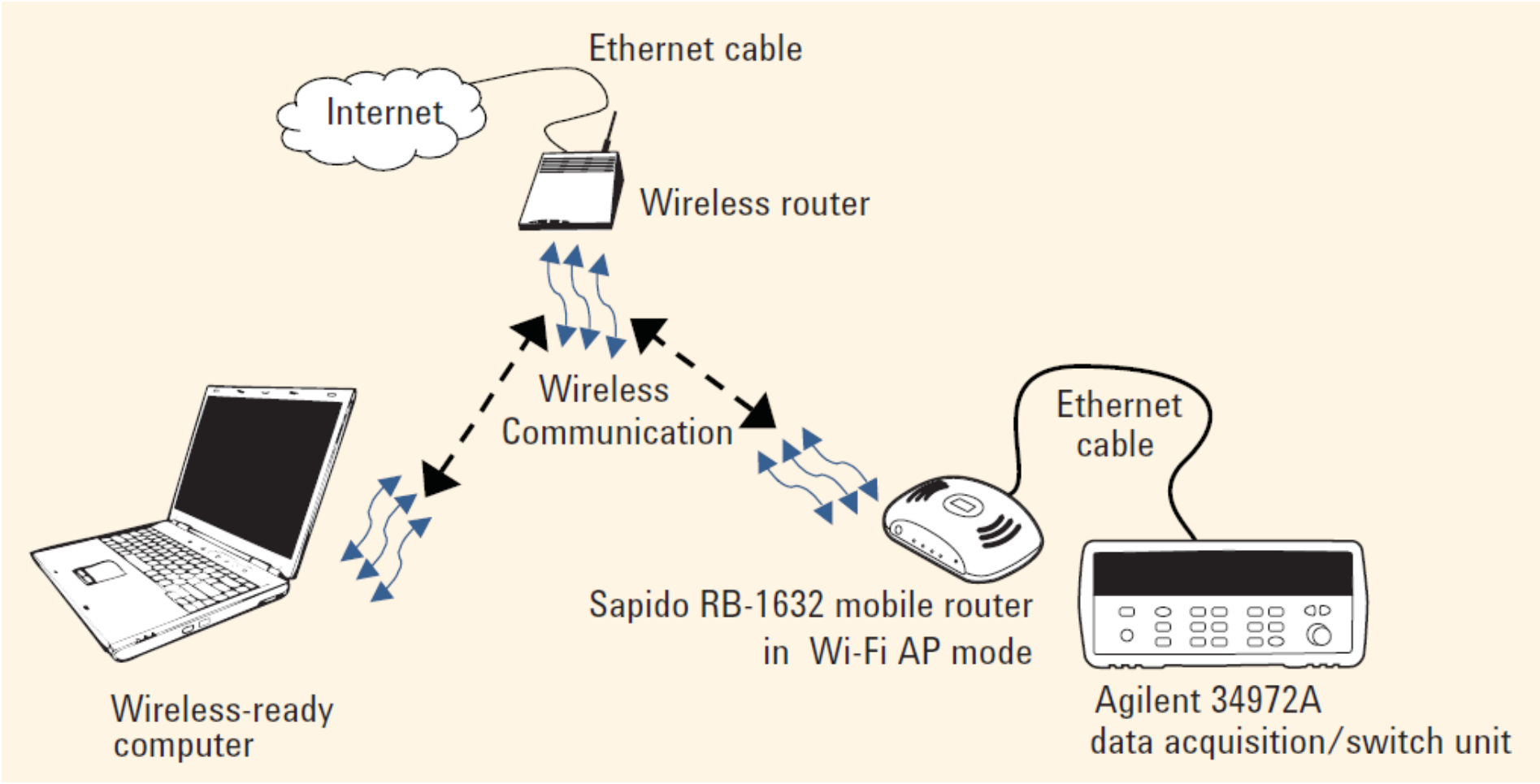
Juhtmeteta edastusmuundurid

Signaali vastuvõtja

Andmete edastamine (*wireless*)



Andmete edastamine (*wireless*)



Andmelogerid